BEEF CATTLE

PRODUCTION AND TRADE

EDITORS: DAVID COTTLE AND LEWIS KAHN

BEEF CATTLE

PRODUCTION AND TRADE

EDITORS: DAVID COTTLE AND LEWIS KAHN

CSIRO
PUBLISHING

© David Cottle 2014

All rights reserved. Except under the conditions described in the *Australian Copyright Act 1968* and subsequent amendments, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, duplicating or otherwise, without the prior permission of the copyright owner. Contact **CSIRO** PUBLISHING for all permission requests.

National Library of Australia Cataloguing-in-Publication entry
Beef cattle production and trade / edited by David Cottle
and Lewis Kahn.

9780643109889 (hardback)
9780643109896 (ePDF)
9780643109902 (epub)

Includes bibliographical references and index.

Beef industry – Australia
Meat industry and trade – Australia.
Beef cattle – Australia.
Cattle trade – Australia.
Exports – Australia.
Australia – Commerce.

Cottle, D. J. (David John), 1954– editor.
Kahn, Lewis, editor.

338.1762130994

Published by
CSIRO PUBLISHING
150 Oxford Street (PO Box 1139)
Collingwood VIC 3066
Australia

Telephone: +61 3 9662 7666
Local call: 1300 788 000 (Australia only)
Fax: +61 3 9662 7555
Email: publishing.sales@csiro.au
Website: www.publish.csiro.au

Front cover: Brahman (top) and Hereford (bottom) cattle. Photos courtesy MLA.
Back cover: Nellore (left) and Angus (right) cattle. Photos courtesy P.V.R. Paulino (left) and MLA (right).

Set in 10/13 Minion and Stone Sans
Edited by Adrienne de Kretser, Righting Writing
Cover design by Jenny Cowan
Text design by James Kelly
Typeset by Thomson Digital
Printed in China by 1010 Printing International Ltd

CSIRO PUBLISHING publishes and distributes scientific, technical and health science books, magazines and journals from Australia to a worldwide audience and conducts these activities autonomously from the research activities of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The views expressed in this publication are those of the author(s) and do not necessarily represent those of, and should not be attributed to, the publisher or CSIRO. The copyright owner shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

Original print edition:
The paper this book is printed on is in accordance with the rules of the Forest Stewardship Council®. The FSC® promotes environmentally responsible, socially beneficial and economically viable management of the world's forests.

Foreword

The productivity and profitability of the Australian beef industry depends on continued innovation that is firmly grounded in objective science, is relevant to Australian conditions and provides practical solutions to help cattle producers maintain the position as world leaders in the production of beef. Preparing the next generation of people working in agriculture is critical to the long-term competitiveness and sustainability of the industry.

Meat & Livestock Australia is proud to support *Beef Cattle Production and Trade*, the first textbook in Australia to cover all aspects of beef production in a single volume. It has excellent coverage of the different facets of the Australian industry, as well as an insight into other key beef producing countries across the globe.

Each chapter has been written by experts to ensure readers are informed of the fundamental aspects of Australian beef production. From grazing management to genetics, to environmental management and biosecurity, this textbook covers an extensive scope of topics that demonstrate the complexities of the beef supply chain and the opportunities for various career paths that exist. We hope this book inspires you to pursue a career in the Australian beef industry.

Scott Hansen
Managing Director
Meat & Livestock Australia

This page intentionally left blank

Contents

List of contributors

M.B. Allworth, Fred Morley Unit, Charles Sturt University, Locked Bag 588, Wagga Wagga NSW 2678, Australia.

C.E. Bagshaw, Schuster Consulting Group Pty Ltd., PO Box 75, Dubbo NSW 2830, Australia. Email: scg@schusterconsulting.com.au

K. Behrendt, School of Agricultural & Wine Science, Charles Sturt University, Orange NSW 2800, Australia. Email: kbehrendt@csu.edu.au

C.G. Brown, School of Agriculture and Food Sciences, University of Queensland, St Lucia Qld 4072, Australia. Email: colin.brown@uq.edu.au

H.M. Burrow, CSIRO Animal, Food and Health Sciences, C.J. Hawkins Homestead, University of New England, Armidale NSW 2351, Australia. Email: Heather.Burrow@une.edu.au

M.A. Campbell, E.H. Graham Centre for Agricultural Innovation (NSW Department of Primary Industries and Charles Sturt University), Locked Bag 588, Wagga Wagga NSW 2678, Australia. Email: mcampbell@csu.edu.au

D.J. Cottle, School of Environmental and Rural Science, University of New England, Armidale NSW 2351, Australia. Email: dcottle@une.edu.au

M.S. Duarte, Department of Animal Science, Universidade Federal de Viçosa, PH Rolfs Avenue, Viçosa, MG, Brazil.

J. Earl, Agricultural Information and Monitoring Services, 'Glen Orton', Coolatai NSW 2402, Australia. Email: judi@aimsag.com.au

J.B. Gaughan, School of Agriculture and Food Sciences, University of Queensland, Gatton Qld 4343, Australia. Email: j.gaughan@uq.edu.au

A.D. Herring, Department of Animal Science, Texas A&M University, College Station, Texas 77843–2471, USA. Email: andy.herring@tamu.edu

B.W.B. Holman, Animal Science and Genetics, School of Agricultural Science, Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 54, Hobart Tas 7001, Australia.

R.G. Holroyd, Department of Agriculture, Fisheries and Forestry, PO Box 6014, Red Hill, North Rockhampton Qld 4701, Australia.

D.L. Hopkins, Centre for Red Meat and Sheep Development, NSW Department of Primary Industries, Cowra NSW 2794, Australia. Email: David.Hopkins@dpi.nsw.gov.au

P.I. Hynd, School of Animal and Veterinary Sciences, University of Adelaide, Roseworthy Campus, Roseworthy SA 5371, Australia. Email: philip.hynd@adelaide.edu.au

T. Jackson, Australian Bureau of Agriculture and Resource Economics and Sciences, Canberra ACT, Australia.

B.J. King, E.H. Graham Centre for Agricultural Innovation (NSW Department of Primary Industries and Charles Sturt University), Locked Bag 588, Wagga Wagga NSW 2678, Australia.

M. Komatsu, National Institute of Livestock and Grassland Science, Tsukuba, Ibaraki, 305–0901, Japan. Email: mkomatsu@affrc.go.jp

M. Laurence, Murdoch University – College of Veterinary Medicine, South St, Murdoch WA 6150, Australia. Email: m.laurence@murdoch.edu.au

I. Lean, SBScibus, 2 Broughton St, Camden NSW 2570, Australia.

A.E.O. Malau-Aduli, Animal Science and Genetics, School of Agricultural Science, Tasmanian Institute of Agriculture, Faculty of Science, Engineering and Technology, University of Tasmania, Private Bag 54, Hobart Tas 7001, Australia. Email: Aduli.MalauAduli@utas.edu.au; and School of Veterinary and Biomedical Sciences, Faculty of Medicine, Health and Molecular Sciences, James Cook University, Townsville, Qld 4811, Australia.

B. Malcolm, Department of Agriculture and Food Systems, University of Melbourne, Melbourne Vic 3010, Australia.

M.R. McGowan, School of Veterinary Science, University of Queensland, Gatton Qld 4343, Australia. Email: m.mcgowan@uq.edu.au

R. Mulley, School of Science and Health, University of Western Sydney, Locked Bag 1797, Penrith NSW 2751, Australia.

D.A. Norton, School of Forestry, University of Canterbury, Christchurch 8140, New Zealand. Email: david.norton@canterbury.ac.nz

P.V.R. Paulino, Global Technology Manager for Beef Cattle – Nutron/Cargill Animal Nutrition, 150 José Bonifácio Coutinho Nogueira Ave, Galleria Plaza, Campinas SP, Brazil. Email: pedro_paulino@cargill.com

W.S. Pitchford, School of Animal and Veterinary Sciences, University of Adelaide, Roseworthy SA 5371, Australia. Email: wayne.pitchford@adelaide.edu.au

D.P. Poppi, School of Agriculture and Food Sciences and School of Veterinary Science, University of Queensland, Gatton Qld 4343, Australia. Email: d.poppi@uq.edu.au

N. Reid, Ecosystem Management, School of Environmental and Rural Science, University of New England, Armidale NSW 2351, Australia. Email: nrei3@une.edu.au

B.J. Santich, School of History and Politics, University of Adelaide, Adelaide SA 5005, Australia. Email: barbara.santich@adelaide.edu.au

P.E. Schuster, Schuster Consulting Group Pty Ltd., PO Box 75, Dubbo NSW 2830, Australia. Email: scg@schusterconsulting.com.au

M. Stafford Smith, CSIRO Climate Adaptation Flagship, PO Box 1700, Canberra ACT 2601, Australia. Email: Mark.Staffordsmith@csiro.au

M.L. Sullivan, School of Agriculture and Food Sciences, University of Queensland, Gatton Qld 4343, Australia. Email: megan.sullivan@uqconnect.edu.au

S.A. Waldron, School of Agriculture and Food Sciences, University of Queensland, St Lucia Qld 4072, Australia. Email: Scott.Waldron@uq.edu.au

V.E. Wright, Business School, University of New England, Armidale NSW 2351, Australia.

1 Beef consumption: historical overview, recent trends and contemporary attitudes

B.J. Santich

CONTEMPORARY BEEF CONSUMPTION

In 2012 beef consumption varied widely across the globe, from slightly more than 1 kg per capita annually in Bangladesh to 54 kg per person annually in Argentina and Uruguay (USDA 2011). Consumption levels are typically dependent on there being a tradition of beef production, which may be associated with religious beliefs, and household income. In Australia and the USA, all three factors play significant roles, but in other countries, one factor may predominate. For example, in 2011, per capita consumption of beef and veal in Hong Kong was only slightly less than in Australia even though Hong Kong produces very little beef and is almost totally dependent on imports of beef and live cattle. However, Hong Kong is among the top 20 countries in terms of gross national income per capita (World Bank 2013).

According to the US Department of Agriculture (USDA 2011), the top 10 beef-consuming countries in October 2011 were Argentina, Uruguay, Brazil, the USA, Paraguay, Australia, Hong Kong, Canada, New Zealand and Kazakhstan. In these countries, per capita consumption was more than 26 kg per annum. In the six highest-ranking countries, per capita consumption exceeded 34 kg per annum (Table 1.1). Although the order may change from year to year, the same countries have tended to occupy the top six rankings for the past two decades. All are major beef-producing countries or wealthy countries with a high standard of living.

The principal beef-producing countries – Argentina, Australia, Brazil, Canada and the USA (Chapters 5 and 6), but excluding China – together accounted for 43% of world beef production in 2011 (FAOSTAT 2013; Fig. 1.2) and are all significant beef consumers, with beef representing at least one-third of total per capita meat and poultry consumption. However, cattle are not indigenous to any of these countries; beef production and consumption are imported traditions. In the case of Australia, Canada and the USA, these traditions originated in England, where beef has been a popular and valued meat

Table 1.1: Beef and veal consumption 2011, selected countries

Country	kg per capita per year
Argentina	54.0
Uruguay	53.9
Brazil	37.6
USA	37.4
Paraguay	37.0
Australia	34.2
Hong Kong	32.3
Canada	29.2
New Zealand	28.0
Kazakhstan	26.5
Chile	25.9
Uzbekistan	21.7
Colombia	19.0
Venezuela	18.8
Mexico	17.8

Source: USDA Foreign Agricultural Service (2011).

Figure 1.1: Cattle being grazed on pasture. Source: Cattle Council of Australia.

for many centuries. From at least the 16th century, beef was the most prestigious meat in England and it was the most common meat in the British diet until the mid 1960s (Rogers 2003; National Food Survey 2011).

In the past few decades, consumption has tended to decrease in traditional beef-producing and beef-consuming countries such as Australia and the USA in concert with a general decrease in red meat consumption and an increase in poultry consumption (Table 1.2). In contrast, red meat consumption has increased in countries that do not have a long history of beef consumption, mainly because of increased affluence, greater affordability of beef and Westernisation of diets and eating habits. In Taiwan, for example, average per capita consumption doubled between 1992 and 2011, albeit to only 6.0 kg per year (FAOSTAT 2011).

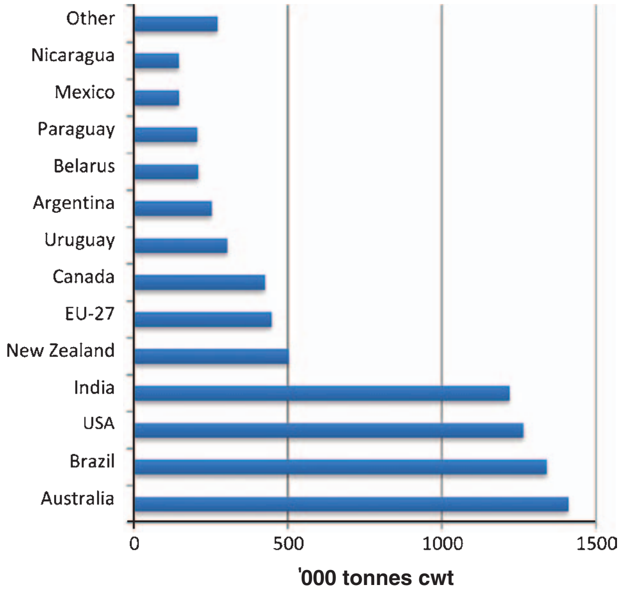


Figure 1.2: Major beef-exporting countries, 2011. Source: Meat and Livestock Australia (2011).

MEAT CONSUMPTION TRENDS IN THE 20TH CENTURY

Beef consumption is generally associated with developed countries and with high levels of total meat and poultry consumption (Table 1.2).

Although there was no consistent global trend in respect of beef between 1961 and 2007, poultry supply in all countries listed in Table 1.2 was significantly greater in 2007 than in 1961. In almost all countries, poultry's share of total meat supply increased between 1961 and 2007; in Israel, poultry accounted for 69% of the total meat supply of 99 kg per person in 2007.

FAO data are a useful guide to relative levels of consumption in various countries, but it is important to acknowledge the inaccuracy of consumption estimates because they are based on data on production, exports, imports and changes in stocks. Consumption statistics based on weekly purchases for a large sample of households, such as those compiled by the British National Food Survey, provide a closer

Table 1.2: Meat supply: selected countries (kg per person per year)*

	Beef 2007	Beef 1961	Pork 2007	Pork 1961	Poultry 2007	Poultry 1961	Total meat 2007	Total meat 1961
Argentina	54.89	83.20	6.75	8.67	26.70	2.04	91.42	101.72
Australia	44.01	41.17	23.27	10.32	39.77	4.79	122.70	103.72
Bahamas	19.15	30.95	24.45	19.98	46.46	9.00	96.58	64.03
Bermuda	27.49	50.43	18.84	14.70	30.29	16.63	81.62	87.15
Brazil	37.16	17.60	11.01	7.01	31.66	1.73	80.49	27.50
Canada	32.83	36.66	27.38	26.28	37.45	13.86	98.83	78.67
Denmark	26.69	16.59	47.94	35.61	18.26	7.26	98.20	61.03
France	26.80	28.59	31.76	25.97	21.10	11.05	88.77	77.05
Fr. Polynesia	40.18	15.30	13.55	8.23	46.40	2.50	108.61	26.91
Israel	27.08	7.73	2.61	1.72	67.80	19.32	98.89	30.00
Italy	24.12	14.86	44.83	7.88	15.86	5.37	91.65	30.99
Kazakhstan	26.46	n.a.	15.20	n.a.	13.41	n.a.	67.54	n.a.
Luxembourg	43.83	n.a.	45.53	n.a.	39.91	n.a.	136.73	n.a.
Malta	21.37	17.63	37.37	9.55	24.81	3.13	89.93	32.37
Mongolia	16.26	44.57	0.15	n.a.	0.54	0.20	68.36	144.84
New Zealand	32.14	47.06	22.91	15.30	34.70	2.67	116.81	107.65
Norway	20.48	15.42	23.06	28.99	14.88	0.69	65.42	52.12
Portugal	18.25	6.21	44.93	9.07	25.29	1.60	92.62	20.04
Slovenia	21.44	n.a	41.02	n.a.	19.91	n.a.	83.93	n.a.
South Africa	16.36	20.35	3.54	3.07	24.98	1.93	48.87	32.24
Spain	15.12	5.98	61.66	7.96	27.61	2.65	111.56	21.78
Sweden	23.99	19.58	36.45	24.95	14.78	2.70	78.68	50.66
Switzerland	20.57	23.62	34.32	26.44	14.98	4.37	73.68	56.64
UK	21.95	24.93	27.79	25.37	29.06	6.31	85.51	69.44
USA	41.23	41.24	29.68	27.70	50.69	16.44	122.79	88.69
Uruguay	15.21	75.92	9.33	7.00	14.07	2.94	43.13	107.80
Uzbekistan	20.50	n.a	0.85	n.a.	1.04	n.a.	25.62	n.a.
Venezuela	20.98	16.48	5.95	4.67	28.70	5.25	75.77	27.30

Source: FAOSTAT (2011).

* These figures represent estimates of food supply in selected countries and tend to overestimate actual consumption; nevertheless, they have the advantage of providing a degree of historical consistency.

approximation of consumption, but even these include a margin for error (Prynne *et al*. 2009). Recent research shows that the latter method may overestimate actual meat consumption by 43% because purchases may include bone and other non-edible components and because proportions of meat vary between composite meat-containing dishes (Prynne *et al*. 2009). The estimates quoted in the following paragraphs are all associated with varying margins of error in relation to actual consumption.

Although beef consumption estimates vary widely from country to country, Australia, Britain and the USA experienced similar trends over the course of the 20th century, and similar factors were responsible for these changes. In these countries, beef consumption peaked and then decreased as chicken and pork assumed an increasing share of total meat and poultry consumption. In Brazil, on the other hand, strong economic growth in recent years increased beef consumption (per capita supply) more than two-fold between 1961 and 2007.

At the end of the 19th century, Australians had the enviable reputation of being the greatest consumers of meat in the world; at this time, 'meat' was construed as beef and mutton. Citing New South Wales government statistician T.A. Coghlan, Dr Philip Muskett reported that annual per capita meat consumption ranged from 275 lb (125 kg) in Victoria and 291 lb (132 kg) in New South Wales to 371 lb (169 kg) in Queensland. In comparison, the British consumed 109 lb (49.5 kg) of meat per year, Americans consumed 150 lb (68 kg) of meat per year and Europeans consumed less than 70 lb (32 kg) of meat per year (Muskett 1893). Meat consumption in New South Wales decreased from 124 kg in 1912 to 79 kg in 1919/20, but subsequently increased until the eve of World War II (Santich 1995).

The first official national estimates of apparent meat consumption in Australia date from the mid 1930s. Over the three years ending 1938/39, average annual per capita meat consumption (no estimates were available for poultry consumption) was 107 kg (carcass weight equivalent), beef accounting for 59% (64 kg) of the total (ABS 2000). Historically, Australians consume more beef and veal than mutton and lamb, but in the late 1960s both were equally popular. After a slight decrease in the 1940s, beef consumption increased again to a peak of 70 kg in 1977, but then decreased to 36 kg in 2009/10 (ABARE 2009). Significantly, chicken overtook beef as the nation's most popular meat in 2005 (Fig. 1.3).

In the USA, beef consumption also peaked in the 1970s, reaching 58 kg per person plus 1.8 kg veal (carcass weight) in 1976. For much of the first half of the 20th century, Americans ate more pork than beef, but from the early 1950s, as hamburger chains spread across the country, beef became the dominant meat. Between 1951/55 and 1961/65, average annual per capita consumption increased by 29%, and much of the beef consumed was in the form of hamburgers. In the early 1980s, Americans ate nearly 23 kg of ground beef annually, mostly in the form of hamburgers (Harris 1987). Poultry consumption began to increase during this period and by the mid 1990s had overtaken beef and veal consumption. The decrease in beef and veal consumption after 1976 was gradual and in 2009 Americans consumed 40 kg of beef and veal per person. This is roughly the same as the amount consumed in the early 1960s, and slightly less than half of the beef and veal consumed was in the form of ground beef. According to Schlosser (2001), American adults ate three hamburgers per week in the 1990s. In 2009, beef constituted only 33% of total meat and poultry consumption, compared with nearly 50% at the beginning of the 20th century and 54% in 1976 (USDA Economic Research Service 2011).

British beef consumption trends are generally consistent with those in Australia and the USA, although the base point is considerably lower in the UK. A series of surveys, mainly of working-class families, at the end of the 19th century indicated that total meat consumption in England ranged from 21 kg per person per year for the poorest households to 76 kg for households that could afford to employ servants (Oddy 1970). Annual meat consumption increased until 1939, but decreased after the introduction of rationing in 1940 to a nadir of 34 kg in 1949. In 1952, annual beef consumption was only 8.8 kg per person. Although meat rationing remained in force until 1954, consumption increased during the 1950s, beef consumption reaching 16 kg (30% of total meat consumption) in 1957. Twenty years later, beef's share of total annual meat and poultry consumption in Britain had fallen to 20% and in 2000, at 6.5 kg, constituted only 13%.

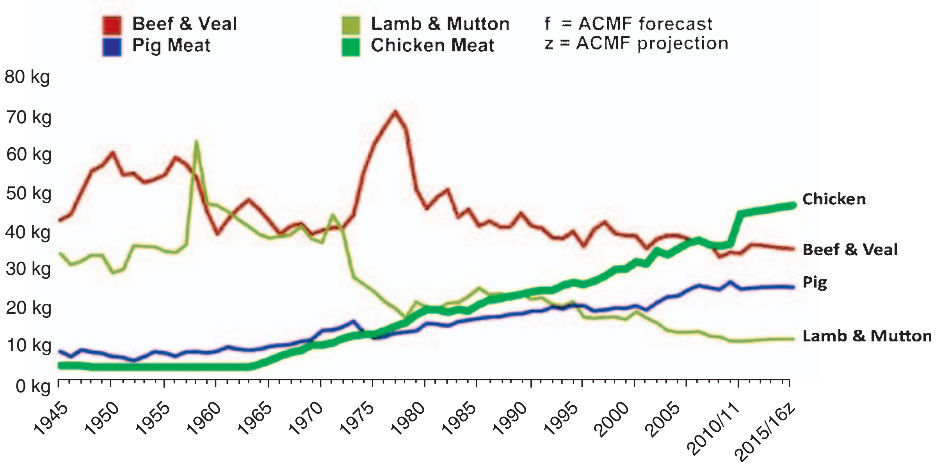


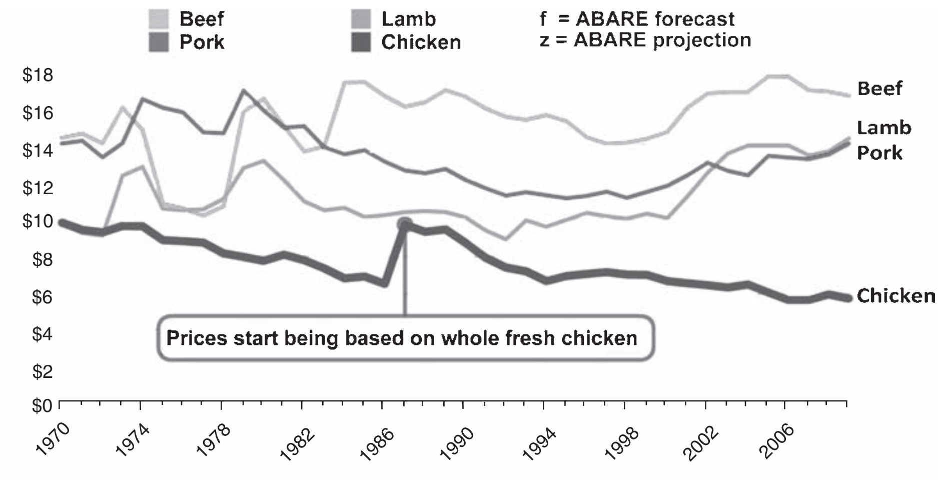
Figure 1.3: Consumption of various meats in Australia. Source: Australian Chicken Meat Federation (2012).

Pork consumption remained at a high level after rationing ceased, exceeded that of beef and poultry by the mid 1960s and constituted 26% of total meat and poultry consumption in 2000 (National Food Survey 2011). Data from the 2008/2009 National Diet and Nutrition Survey, which relied on a methodology that differed from that used in the National Food Survey, suggest that consumption of red and white meat across all age groups and sexes has increased during the 21st century (Wyness *et al.* 2011). Corroborating this trend, data from the Family Food Survey indicate that purchases of beef and veal increased between 2008 and 2009 (Wyness *et al.* 2011).

Of the countries that comprise the European Union, France, which is also a significant beef producer, had the highest per capita beef consumption (25 kg carcass equivalent) in 2009, but this value is much lower than that for Australia or the USA. Overall, French per capita meat consumption rose steadily from 1970 but decreased by 7% from 1998 to 2009. Much of this decrease was accounted for by a decrease in beef consumption, which constituted only 29% of total meat consumption in 2009 compared with 39% in 1970. In contrast, pork held its share of ~39% of total meat consumption and that of poultry increased from 16% to 28% of total meat consumption (FranceAgriMer 2010).

Similar factors were responsible for decreases in beef consumption in various countries. In the 1970s, health authorities often advised people to eat less red meat because of its association with high circulating levels of saturated fatty acids and cholesterol, both of which are associated with coronary heart disease. In Australia, for example, the National Heart Foundation encouraged consumers to switch to white meats such as chicken, veal and fish. *Polyunsaturated Cookery*, published by the National Heart Foundation in 1974, included 27 recipes for chicken and veal and eight for fish, but only 15 recipes for beef and 18 for lamb (Santich 1995). In subsequent decades, the ideal healthy diet was based on the inclusion of unrefined or minimally processed carbohydrates to lower fat intake. Whether intentionally or not, this concept also had the effect of reducing the quantities of meat in the diet. In 1998, the *Australian Guide to Healthy Eating* recommended that adults eat red meat three to four times per week, a serving size being 65–100 g of cooked meat which would amount to an annual consumption of 10–21 kg per capita. This represents a significant change from the eating habits of the 1950s and 1960s, when red meat would typically be eaten every day of the week and in larger amounts (Children's Health Development Foundation 1998).

These health-motivated changes occurred at a time when the availability of chicken was increasing. Since the introduction of intensive poultry farming practices in the mid 1960s, Australian production has increased more than 10-fold (Australian Chicken Meat Federation 2012). Chicken was also more convenient to buy because it was available in supermarkets; in Australia supermarkets were selling fresh chicken meat and chicken portions well before expanding into the full range of butcher meats. Consumers liked the versatility of chicken, its reliability in terms of eating qualities, that it is quick and easy to



Note: The above chicken price statistics relate to the price per kg of whole chickens. Prior to 1987, the price of frozen whole chickens were recorded, while from 1987 onwards the price of fresh whole chickens is being reported. This change was made because frozen whole chickens have now become a minor component of chicken sold. This change explains the jump in the price reported between 1986 and 1987.

Figure 1.4: Retail price of meats, Australia. Source: Australian Chicken Meat Federation (2012).

cook, and, perhaps most of all, its low price (Dixon 2002; Fig. 1.4). In 2009, the average price of chicken in France was less than half that of beef (FranceAgriMer 2010).

Whereas the price of beef and other red meats in Australia has increased, that of chicken has decreased in real terms, partly as a result of more efficient feed conversion reducing the cost of production, but also because of a high degree of vertical coordination in the chicken industry. In 2010 dollars, the price of chicken in Australia has fallen since 1970 whereas beef, lamb and pork prices have increased (Australian Chicken Meat Federation 2012*)*. Since 1986, the retail price of beef has more than doubled but the average price of chicken has increased by only 26%; the price of chicken was equivalent to 60% of that of beef in 1986 and was equivalent to 33% of that of beef in 2009 (ABARE 2009).

The decrease in beef consumption in Australia, the USA, Britain and France since the 1970s can be attributed, in part, to the relatively low price of chicken and its perceived health advantages, but other factors are also relevant. Unlike beef, the quality of chicken is consistent and its versatility and ease of cooking are seen as appropriate to modern lifestyles. For similar reasons, pork has also supplanted red meats such as beef and lamb. Compared with the 1970s, pork now constitutes a greater proportion of total meat consumption in Australia and the USA; its share of total meat consumption has decreased slightly in England and has remained unchanged in France.

However, beef consumption in many other countries has increased in recent decades, albeit from a relatively low base, typically as a result of improved living standards and increased incomes in association with globalisation of trade. In these instances, the increase in beef consumption tended to occur in the context of higher meat and poultry consumption in general and a better standard of nutrition overall. This trend, contrary to that in many traditional beef-consuming countries, is evident in oil-rich countries such as Saudi Arabia and the United Arab Emirates and in developing Asian countries such as China, South Korea, Malaysia, Taiwan and Vietnam. Nevertheless, consumption in these countries remains considerably lower than in the principal meat-consuming countries.

HISTORICAL EVOLUTION OF BEEF CONSUMPTION

In the ancient and early medieval world, meat was a luxury reserved for the higher ranks of society or for special occasions associated with religious practices and sacrifices. In the 5th century BC, meat consumption in Greece was associated with animal sacrifice. Rules governing the sale of meat specified that it must be derived from a sacrificial killing; it could not be derived from animals that were not sacrificed or from animals whose sacrifice was not permitted (Detienne 1989).

The association between cattle and religion can be traced back to very early times. Bull-gods were worshipped in the Sumerian and ancient Egyptian civilisations, and Egyptians subsequently installed cow-goddesses, representing motherhood and nurture (Velten 2007). Bull-gods were typically associated with strength, ferocity and fertility. By causing rain and storms, they made rivers flood, replenishing soil fertility (Velten 2007). The Aryan society of early India also worshipped and sacrificed cattle and ate beef until ~600 BC, when supplies were insufficient for the growing population and consumption was restricted to the higher castes and priests. The subsequent centuries-long peasant revolt was settled only when Hinduism reversed its position on sacrifice, condemning the ritual slaughter of cattle and encouraging the worship of cows (Rifkin 1992). To this day, Hindus abstain from eating beef.

In the early Roman Empire, the followers of Mithras, the bull slayer, cattle thief and sun god, sacrificed a bull – or occasionally a sheep – and subsequently ate the meat. This kind of sacrifice, typically recorded on a 'taurobolium' inscribed with the date and the name of the person who made the sacrifice, was quite different from the earlier Greek sacrifices in that the animal was sacrificed and slaughtered over a deep pit so that its blood showered the worshipper below (Rimas and Fraser 2008). Nevertheless, sacrifice and consumption were intimately and symbolically linked.

By the 5th century AD, meat was no longer the product of sacrifice and was readily available to the citizens of Rome; although expensive, it was not a rarity reserved for the elite. Excepting slaves and the poor, Romans probably consumed 20–25 kg of pork, beef and mutton per person annually, and meat was part of a soldier's customary diet (Corbier 1989). The 6th-century writer Anthimus discussed the properties of the kinds of meat, game and poultry that would have been eaten by the Franks and Gallo-Romans, recommending tender ox, either boiled, steamed or roasted. He commented that salted beef and ox were difficult to digest and recommended that they be eaten only if absolutely necessary (Grant 1996).

European and British meat consumption is believed to have been relatively high during the 14th and 15th centuries because of an increase in stock numbers associated with conversion of crop lands to pasture and because of the decrease in population, associated with a plague in the 14th century. Meat consumption continued at a high level for much of the 16th century then decreased to a low point at the beginning of the 19th century. Thereafter, consumption increased gradually at rates that differed between regions (Livi Bacci 2000). Reasonably accurate estimates of meat consumption rates have been compiled for specific places and times, such as Carpentras (southern France) in the 15th century. Stouff (1970) estimated that the citizens of Carpentras ate 26 kg of meat per year and, although mutton was the principal meat consumed, beef represented ~35–40% of total meat consumption. However, during the same period, the archbishop's household at nearby Arles consumed 66 kg of meat annually. Another study (Montanari 1994) suggested that average annual meat consumption in French and Italian cities was 20–40 kg. Average annual meat consumption in late medieval Germany is estimated to have exceeded 100 kg per person, much of this meat coming from Poland, Hungary and the Balkan countries (Rifkin 1992; Livi Bacci 2000).

From about the mid 16th century, increasing population pressure resulted in a decrease in meat consumption; by the mid 17th century, the Catholic calendar had increased the number of meatless days to nearly half the days of the year (in the 14th century it was about one-third of the days of the year) (Rifkin 1992). At the end of the 17th century, the English consumed 33 kg of meat per person annually, but this average conceals vast discrepancies; more than half the population ate meat only once a week or never, whereas the rest of the population consumed meat on at least five days per week (Livi Bacci 2000). In France and Germany, both of which had relatively high numbers of livestock, per capita meat consumption was 14–20 kg per year at the low point in the first decades of the 19th century (Montanari 1994).

Estimates of total meat consumption in Europe tend to obscure regional differences. At the end of the medieval era, two dietary models prevailed, one typical of southern or Mediterranean Europe and the other typical of northern Europe (Portugal, Poland and the British Isles). The inhabitants of southern France, most of Italy and much of Spain consumed a diet based on wheaten bread, mutton, lamb, kid, pork, wine, olive oil and fish. In the rest of Europe, bread was made from rye and barley as well as from wheat. Beef was more commonly consumed than mutton, and pork was often consumed. Cider and beer were drunk instead of, or as well as, wine. Consumption of dairy foods and, in Atlantic regions, fish was greater than in Mediterranean Europe (Bennassar and Goy 1961). Even today these models are still, to some extent, valid.

Developed over many centuries, these dietary patterns reflected the systems of agriculture and land use in southern and northern Europe, which in turn were largely determined by the physical environment. The introduction of the mouldboard plough after the 11th century was beneficial to northern Europe. It was appropriate for the heavy soils, penetrating deeper and turning the sod. It enabled the cultivation of larger areas of land, encouraged a three-year crop rotation system and, by spreading the risk over two crops each year, improved the reliability of the food supply. However, the mouldboard plough required animal power in the form of horses or oxen. Feed was provided for these animals by including oats in the crop rotation schedule. In Mediterranean regions, the lack of summer rains and the need to conserve soil moisture favoured the continued use of the simple furrow plough, which did little more than break up the soil surface. Consequently, the standard farming system remained a soil-exhausting, low-yield, high-risk, two-year rotation crop and fallow system. In addition, consistently low cereal yields obliged farmers to adopt a system of polyculture in which fruit and nut trees were integrated with crops and pastures to compensate for irregular and low cereal yields (Santich 1988).

Cattle, whether milking or draught, were clearly more compatible with the farming practices of northern Europe and it is logical that their products would feature more strongly in diets typical of this region. It is also possible that the northern European beef was superior in quality to that of the Mediterranean region, although neither would have borne comparison with the beef of today. Certainly, beef (but not veal) typically sold at lower prices than mutton in Mediterranean regions, although this could also have been a reflection of Mediterranean food preferences (Santich 1988).

The stereotypical association between England and beef was well established by the 16th century when Andrew Boorde recommended beef as the ideal meat for Englishmen in his 1542 *Dyetary* (Rogers 2003). Even earlier than this, the Celts assessed wealth in terms of cattle numbers and beef was the preferred meat of the occupying Romans (Rifkin 1992). The English probably ate more beef than the French in the 16th century, although consumption would have been largely restricted to the upper and middle classes (Rogers 2003). According to Henry Peacham, in the early 17th century, 'our City of London, of it self alone, eateth more good beef and mutton in one Moneth than all Spain, Italy and a part of France in a whole year' (Edwards 2008). French traveller Henri Misson observed of the English in 1698 that 'It is common Practice, even among people of good Substance, to have a huge Piece of Roast-Beef on Sundays, of which they stuff until they can swallow no more, and eat the rest cold, without any other Victuals, the other six Days of the Week' (Velten 2007). By the end of the 17th century, those English who could afford the luxury of meat chose beef (Rogers 2003; Velten 2007). The reputation of beef as patriotically English continued to develop in subsequent centuries and was epitomised by the institution in 1735 of the Sublime Society of Beefsteaks, the motto of which was 'Beef and Liberty' (Rogers 2003).

English cattle changed little between the days of the Romans and the early 17th century, although management systems improved (Wilson 1973). During the medieval period, stock were slaughtered in autumn to avoid the cost of winter feeding, but by the 16th century nobles were fattening store cattle on their estates and cattle owners in north and west England drove their cattle to major towns for fattening before they were sold to butchers (Wilson 1973). From the mid 17th century, winter-feeding practices and new legumes increased animal growth rates, which avoided the need to slaughter in autumn (Wilson 1973). The quality of English beef (especially in comparison with French beef) was frequently noted. In the mid 18th century, the Swedish–Finnish botanist and agricultural economist Pehr Kalm wrote: 'Roast meat is the Englishman's delice and principal dish … All English meat, whether it is of ox, calf, sheep or swine, has a fatness and a delicious taste, either because of the excellent pasture, which consists of such nourishing and sweet-scented kinds of hay as there are in this country, where the cultivation of meadows has been brought to such high perfection, or some way of fattening the cattle known to the butchers alone, or for some other reason' (Wilson 1973).

Until the late 18th century, the British cattle herd was a miscellany of local strains rather than standard breeds. They were described as large, long-bodied and big-boned, but they were relatively slow-growing and did not produce enough meat to feed a growing and increasingly affluent population (Velten 2007). Robert Bakewell, a Leicestershire farmer who, before taking over the family farm, had travelled in Europe to learn about other farming practices, realised that a market existed for beef of better quality than that obtained from the slaughter of animals that had passed their prime after producing milk or pulling ploughs. Bakewell's innovation was to focus on breeding and potential meat production by selecting and breeding animals that yielded more meat in a shorter period. His cattle were low-set, blocky and matured early; he regarded colour and size as irrelevant. Although he concentrated his efforts on selective breeding, he also introduced pasture irrigation, winter fodder crops, the use of manure to fertilise crops and pasture rotation (Carlson 2001).

By the 1780s, Bakewell had developed a cattle breed known as the Improved Longhorn, although this was soon superseded by the dual-purpose Shorthorn (Velten 2007). His example encouraged other English gentleman farmers to embrace animal breeding, almost as an educated hobby, which resulted in competitions, shows and the development of breed societies. The ideal beast was large and fat; the Durham ox, an improved Shorthorn that toured England in 1800, weighed 3210 lb (1456 kg) (Velten 2007). As a result, the English developed a taste for fatty, well-marbled beef and the weight of cattle more than doubled between the late 18th and early 19th centuries (Rifkin 1992).

At the same time as Bakewell's experiments, the Enclosure Acts of the late 18th and early 19th centuries, which favoured individual ownership of land, effectively removed a significant proportion of land from common use and arable land was converted to pasture, which was more profitable. As a result, small tenant farmers lost their lands or migrated elsewhere and cottagers who might have kept a cow on the commons had nowhere to pasture their animals. The result was that animal production fell to a smaller number of producers while the number of consumers increased. By the end of the 19th century, pastures were overgrazed and herds had been decimated by rinderpest, which forced the British to import beef from new beef-producing regions such as Australia, the USA and South America (Rifkin 1992).

Longhorn cattle were introduced into the Americas by the Spanish and Portuguese in the 16th century and became the basis of the Texan cattle industry. It was not until the late 19th century that improved British breeds, especially Herefords, became the dominant breeds in the USA (Velten 2007). These early cattle, like the early British cattle, yielded relatively little meat and little profit. With the expansion of the rail system in the 1860s, Texan cattle could be driven north to fatten and then be transported to the vast Chicago stockyards and the large consumer market in north-east America (Velten 2007). The introduction of refrigeration, which initially involved the use of ice, enabled carcasses rather than live animals to be sent from Chicago to the east-coast cities. As shippers were able to profitably sell this beef at lower prices than locally slaughtered beef, the consumption of beef increased (Carlson 2001). By the start of the 20th century, the USA had surpassed England as the top beef-consuming nation (Rifkin 1992). A secondary consequence of this change in the slaughtering and marketing system was the development of more refined ways of dividing the carcass (Horovitz 2006). Cuts such as the porterhouse, T-bone and rib-eye originated in the USA in the late 19th and early 20th centuries. The spread of the hamburger culture, following popularisation of the meat grinder in the late 19th century, also promoted beef consumption, the hamburger being required by law to be made entirely from beef (Smith 2008).

Similarly, cattle were introduced into Australia by the first European settlers. They were imported from the Cape of Good Hope and were probably Bantu cattle (Parsonson 1998). British breeds were introduced from the beginning of the 19th century but even in the 1820s cattle in the colony of New South Wales represented an indiscriminate mix of breeds, mostly derived from the Bengal breed (Parsonson 1998). However, the Shorthorn and Hereford breeds dominated the national herd by the end of the century. The devastating impact of cattle ticks in northern Queensland stimulated research into cross-breeding using Zebu and British breeds in the early 20th century, resulting in a large increase in cattle numbers from the 1950s (Chapter 9). Brahman and Brahman-cross cattle now represent almost half of the national herd and dominate the live cattle trade (Chapter 12).

Throughout history, meat has enjoyed the status of a superior food, initially through its association with religion and ceremony. In addition, its high cost generally meant that consumption was reserved for, or more frequent among, the wealthy and powerful, reinforcing the link between meat and social status. From the medieval era, it became ‘a symbol of power, a tool for generating vigour, physical energy and the ability to do combat, qualities which constituted the primary legitimation of power’ (Montanari 1994). Eating meat has been seen as representing human power over nature and human subjugation of the environment and the natural world. Beef, in particular, is associated with red-bloodedness, masculinity, virility and sexuality (Fiddes 1991). French sociologist Roland Barthes claimed that steak is ‘the heart of meat, it is meat in its pure state; and whoever partakes of it assimilates a bull-like strength’ (Barthes 1972). These symbolic qualities persist in contemporary society, albeit possibly in attenuated form; French respondents in a European study reported that beef provided ‘strength, energy and vitality’ and that ‘a meal has to give you power, you have to eat red meat’ (Van Wezemael *et al.* 2010).

NUTRITIONAL QUALITIES OF BEEF

Historically, the nutritional value of beef has had little influence on its consumption. This is hardly surprising given that the science of human nutrition is barely a century old. In *Food and Feeding*, first published at the end of the 18th century, Sir Henry Thompson described the essential components of foods simply as ‘proteids’, hydrocarbons (fats), carbohydrates and minerals. Vitamins had not yet been identified (Thompson 1901).

Technological advances have facilitated detailed characterisation of the nutritional qualities of beef. It is an important source of high-quality protein, conjugated linoleic acid, B-vitamins, choline, zinc and iron; results from the US National Health and Nutrition Examination Survey (NHANES) 1999–2004 indicate that, among adults aged 19 to 50, lean beef contributed 3.9% to total energy, 4.5% to total fat, 3.8% to saturated fatty acids, 13% to cholesterol intake, 15% to protein, 25% to vitamin B12, 23% to zinc and 8% to iron (Zanovec *et al.* 2010). In addition, beef consumers who chose beef with the highest lean and lowest fat content ate, on average, 125 g beef per day and had significantly higher total protein intake than non-beef consumer (Nicklas *et al.* 2012). For American children and adolescents, lean beef contributes significantly to intake of protein, monounsaturated fatty acids and other key nutrients, and is positively associated with total dietary intake of important nutrients (O’Neil *et al.* 2011). Beef protein is of high biological value, containing all eight essential amino acids (lysine, threonine, methionine, phenylalanine, tryptophan, leucine, isoleucine and valine). In the USA, a 3 ounce (85 g) portion of lean beef supplies 50% of the daily protein requirements (as determined by daily value) (Roussell and Kris-Etherton 2012).

The proportion of fat in standard Australian boneless cuts ranges from 2% (stir-fry) to 23% (porterhouse). According to Williams (2007), an edible portion of

Australian beef trimmed of external fat has a slightly higher content of unsaturated fatty acids (monounsaturated and polyunsaturated) than saturated fatty acids. In the USA, beef is the single largest source of monounsaturated fatty acids in the diet; further, one-third of the saturated fatty acids in beef consists of stearic acid which has no effect on serum cholesterol levels (Nicklas *et al.* 2012).

The ratio of omega-6 to omega-3 fatty acids in beef is significantly less than that of skinless chicken and lean pork, although it is a poor source of omega-3 fatty acids, compared with fish. Diets containing a high level of omega-6 fatty acids and a high ratio of omega-6 to omega-3 fatty acids are associated with cardiovascular disease, various cancers and inflammatory and autoimmune diseases, whereas diets with a high level of omega-3 fatty acids and a low omega-6 to omega-3 fatty acid ratio reduce the risk of these diseases (Simopoulos 2002). It is believed that humans evolved consuming a diet containing approximately equal quantities of omega-6 and omega-3 fatty acids, but in many Western countries today, diets containing omega-6 to omega-3 ratios of ~15:1 are not uncommon (Simopoulos 2002).

Lean beef is a particularly good source of water-soluble B-group vitamins (riboflavin [vitamin B2], niacin [vitamin B3], pantothenic acid [vitamin B5] and vitamins B6 and B12), although it is low in thiamine (vitamin B1) in comparison with pork (Williams 2007). A portion of lean beef weighing 3 ounces (85 g) supplies 18% of average adult daily requirements of niacin and 37% of vitamin B12 (Roussell and Kris-Etherton 2012). Unsurprisingly, beef contains low levels of the fat-soluble vitamins A and D, although beef liver has a high proportion of both vitamin A and folate.

Beef is also rich in the essential minerals iron and zinc; further, the iron in red meat, mostly haem iron, is efficiently absorbed by the human body, a process that is enhanced by the presence of meat protein. Similarly, the zinc is more efficiently absorbed when sourced from a diet rich in animal protein. Beef is the principal source of zinc in the American diet and the third most important source of iron, after enriched bread and cereals (Nutrition Fact Sheet 2003). Among other minerals, selenium is also present in significant amounts, although the concentration may vary according to season and soil. Australian lean raw beef contains 8.1 μg of selenium per 100 g (FSANZ 2010). A 3 ounce (85 g) serve of lean beef contains 39% of the estimated daily adult requirement of zinc, 14% of iron and 24% of selenium (Roussell and Kris-Etherton 2012).

The nutritional value of beef varies slightly according to breed, age, feeding regimen, season and cut. Analyses of lean raw beef from a range of countries indicate that its protein content is 19–23 g/100 g and its fat content is 2–10 g/100 g (Wyness *et al.* 2011). According to the food composition databases used by Wyness *et al.* (2011), French beef has the highest content of total fat, saturated fatty acids and monounsaturated fatty acids (10.4 g/100 g, 4.4 g/100 g and 4.9 g/100 g, respectively) and Italian beef has the lowest contents (2.4 g/100 g, 0.8 g/100 g and 0.8 g/100 g, respectively). The content of selenium varies greatly, from 1.4 μg/100 g in Danish beef to 23.5 μg/100 g in US and Canadian beef (Wyness *et al.* 2011). Mineral content also varies with cut; a study of seven different beef cuts and muscles indicated that zinc content was highest in three rib plate-flank and iron in tri-tip (Cabrera *et al.* 2010).

A US study which compared meat from grass-fed and grain-fed cattle concluded that beef from grass-fed animals had less total fat but more saturated fatty acids than beef from grain-fed animals; it also had a lower omega-6 to omega-3 fatty acid ratio because of a higher content of omega-3 fatty acids (Leheska *et al.* 2008). Australian studies have produced similar results (Ponnampalam *et al.* 2006). Unsurprisingly, Australian beef, which is largely derived from cattle raised on pasture, contains more omega-3 fatty acids than US beef and has a better omega-6 to omega-3 fatty acid ratio. Similar changes in fatty acid composition can be achieved by adding flaxseed to the diet (Kronberg *et al.* 2011).

Nutritional values of beef have also changed over time. In the wake of declining red meat consumption in Australia in the 1980s, the Australian Meat & Livestock Corporation initiated a campaign emphasising the role of lean red meat in a healthy diet and encouraged producers to market leaner animals. In 1988 it introduced a 'carcass attribute pricing' system which favoured moderately lean carcasses compared with very lean and very fat carcasses. From the 1990s, it promoted new, and leaner, cuts of meat (Santich 1995). It seems that these and other strategies – paying more attention to genetics and changing processing and butchering practices – have produced the desired results as the fat content of Australian beef has decreased since the 1980s (Williams *et al.* 2007). In the UK, the fat content of beef has also decreased since the 1970s. According to Lee *et al.* (1995), the average reduction in fat content was ~15% and for some cuts there was a reduction in the fat content of the lean-only portion as well as in the combined lean and fat portions. For example, the fat content of raw rump steak, lean and fat, decreased from 13.5 g/100 g to 9.6 g/100 g (Lee *et al.* 1995).

CURRENT ATTITUDES AND BELIEFS AFFECTING BEEF CONSUMPTION

Changes in the nutritional value of beef have been motivated by changes in consumer attitudes in recent decades. However, despite attempts to improve the healthy attributes of beef and persuasive marketing emphasising the importance of lean red meat to health and well-being, current attitudes towards beef display a degree of ambivalence. This is not only a result of perceived health risks associated with the consumption of beef – the possible link between red meat consumption and cancer and risks associated with saturated fats – but also reactions to certain feeding and slaughtering practices, the risk of food-borne diseases, issues concerning the environment and sustainability, ethical implications and the potential effects of new technologies such as cloning and genetic engineering.

According to numerous surveys, consumers associate the consumption of red meat, including beef, with cancer and heart disease (Van Wezemael *et al.* 2010; Williams and Droulez 2010). This belief may not be justified. In their 2010 review of the risks and benefits of red meat consumption, McAfee *et al.* (2010) discussed a range of studies that have shown an association between red meat consumption and both cardiovascular disease and colon and other cancers. While noting that several studies reported between 1999 and 2008 did demonstrate an increased risk of cardiovascular disease, they also expressed some doubt as to the validity of these results and their relevance today. Methodological limitations include inconsistencies between studies in measuring meat consumption, the inherent bias in estimating consumption and the inclusion of processed meats with red meats. Furthermore, they noted that beef was leaner and had a lower fat content in 2010 than in 2000. They also discussed studies published between 1994 and 2007 that showed a significant association between red meat consumption and colon cancer but again acknowledged inconsistencies in experimental design, in estimating meat consumption and in taking cooking method into account. The authors concluded that red meat consumption is unlikely to be an independent risk factor for cancer and that a decrease in red meat consumption is unlikely to reduce the risk of cancer in the absence of other changes in diet.

McAfee *et al.* (2010) noted that lean red meat contains n-3 polyunsaturated fatty acids, which are beneficial for heart health, although these are present in much lower concentrations than in oily fish. Red meat also contains conjugated linoleic acid, which may have anti-carcinogenic and anti-atherogenic properties. In view of red meat's nutritional contribution – protein, haem iron, zinc, selenium and retinol with a bioavailability superior to that of other foods – the report concluded that red meat should have a place in a balanced diet. Nevertheless, it expressed a note of caution, advising that consumption of red meat should not exceed recommended levels and that consumption of processed meats and meats cooked at a very high temperature should be reduced.

However, public health messages in many countries have highlighted the link between red meat consumption, saturated fats and cardiovascular disease and have encouraged decreased consumption of red meat. A series of Australian surveys in 1993, 1994 and 1995 indicated that an increasing proportion of consumers associated red meat with heart disease (Williams and Droulez 2010). This belief was probably instrumental in influencing a change in dietary practices; a 1999 survey of 1000 respondents found that 45% of men and 54% of women had reduced their intake of red meat and about half the sample reported that the reduction was for health reasons (Williams and Droulez 2010). Furthermore, only 27% agreed that red meat was healthy and almost one-quarter considered red meat unnecessary for a healthy diet (Williams and Droulez 2010). Since 1980, the proportion of Australians trimming fat from meat, or purchasing fat-trimmed meat, doubled to 89% (Williams and Droulez 2010).

Similarly, European research indicates that beef-eating consumers in France, Germany, Spain and the UK are concerned about the fat content of beef and the possible effect of red meat on cholesterol levels (Van Wezemael *et al.* 2010). The consensus opinion of consumers who participated in a series of focus groups in 2008 was that beef is healthy and should be part of a balanced and healthy diet; it was perceived to be particularly important for children. However, they expressed concern about possible carcinogenic effects, although these generally related to amounts eaten, preparation and cooking methods and the presence of harmful residues in the beef. 'Healthful' beef was described as labelled, branded, lean, fresh, 'natural', only slightly processed and properly cooked, whereas 'unhealthful' beef was associated with packaged, canned or further processed beef, beef containing additives or hormones, low-quality or cheap beef, ready-to-eat meals and offal. No clear opinion emerged regarding the healthiness or unhealthiness of organic beef (Van Wezemael *et al*. 2010).

While it is undeniable that red meat consumption has decreased in countries such as the USA, Australia and France, it is debatable whether dietary and health concerns are the only, or indeed the principal, forces motivating consumers. A study of meat consumption in Australia and the USA from 1960s to the 1980s concluded that increased health consciousness alone could not account for the broad changes in consumption patterns and that the trend towards increasing chicken consumption and decreasing meat consumption could be explained by decreasing chicken meat prices and increasing beef prices (Chalfant and Alston 1988). Nevertheless, other health-risk factors may have been involved in the decrease in beef consumption since the 1980s. In the 2008 European survey, consumers expressed concerns about the risk of Creutzfeldt–Jakob disease, which is associated with the consumption of beef from animals infected with bovine spongiform encephalopathy (BSE), as well as possible harmful effects of residues such as antibiotics and hormones (Van Wezemael *et al*. 2010).

Although BSE was identified in cattle in Britain in 1986, the possible link between this disease and a new variant of Creutzfeldt–Jakob disease in humans (V-CJD) was not recognised until 1996 (Fischler 1999). The effect on beef consumption was instantaneous in Britain and Europe; in Britain, Germany and Italy, consumption fell by almost 40% (Fischler 1999). Similarly, in the USA, the impact of the first outbreak of BSE in 2003 was rapid, geographically widespread and economically significant (Schlenker and Villas-Boas 2009). However, in Canada, where BSE was discovered in 2003 and 2005, the response was quite different. Households initially reduced their purchases of beef but this lasted only a couple of months (Ding *et al*. 2011). One possible explanation was the industry-wide response that encouraged Canadians to eat local beef, partly through an advertising campaign and partly through a national barbecue day in July, announced as the 'World's Longest Barbecue' (Blue 2008). Nevertheless, the perceived risk of BSE seems to have diminished. A recent survey of European consumers suggested that concern over the risk of Creutzfeldt–Jakob disease associated with BSE had faded and that trust in beef safety had, to a certain extent, been restored, at least in Europe (de Barcellos *et al*. 2010).

However, the risk of other food-borne diseases may have increased. In the USA and Canada, massive recalls of beef, typically ground beef and hamburger-style products, have occurred because of contamination, or possible contamination, by the bacterium *Escherichia coli* strain O157:H7, which has been responsible for several deaths. In 1997, the US company Hudson Foods voluntarily recalled ~16 million kg of ground beef that had been shown to contain this strain (Schlosser 2001). No studies appear to have examined the impact of such recalls on the demand for beef or on consumption levels, but awareness of the risks and dangers of food-borne diseases may have added to general levels of anxiety about the food supply. The reaction against processed food and modern technology in general is a worldwide trend (Fischler 1999). A study by the European Commission found that although Europeans are generally optimistic about the contribution of technology to quality of life, they are sceptical about its application in the food sector, often because of social, ethical and environmental concerns (Verbeke *et al*. 2010).

Ethical and environmental concerns have a direct influence on food consumption, particularly consumption of foods derived from animals, and consumers are increasingly concerned about the humane rearing, transportation and slaughter of such animals. A European Commission report on the attitudes of consumers towards the welfare of farmed animals concluded that animal welfare is very important to Europeans (Troy and Kerry 2010). According to Tonsor and Olynk (2011), an issue of increasing importance to consumers is whether animals are handled in an 'animal welfare friendly' or 'humane' manner. Their study, based on US data, concluded that media attention to animal welfare issues – animal husbandry and slaughter – had a small but statistically significant negative effect on the demand for beef.

On the other hand, consumers motivated by health, ethics and the environment may turn to beef with specific attributes, e.g. branded or labelled according to origin or grass-fed. US consumers are increasingly interested in forage- or grass-finished beef, for which they are willing to pay a premium. Those who favour production methods that use no additional hormones or antibiotics and those who believe grass-fed beef to be safer than conventional US beef are more likely to pay a premium (Umberger *et al*. 2009). European consumers who believe that the healthiness of beef could be improved by more 'natural' feeding and management and by more humane slaughtering practices qualified both labelled and branded beef as healthful (Van Wezemael *et al*. 2010).

Another factor that may influence future beef consumption is the attitude of consumers towards meat from cloned cattle. Meat from cloned animals is permitted to be sold in some countries (e.g. the UK) but not in Australia or New Zealand (FSANZ 2011). Although authorities in the USA, Europe and Japan have concluded that such meat poses no additional risk compared with meat from conventionally bred animals (Aizaki *et al*. 2011), consumers still show a degree of wariness and reluctance to purchase such meat. Their concerns relate to food safety, the benefits of animal cloning and the welfare of animals used for cloning, which are possibly related to a lack of understanding of cloning. Most believed that meat from cloned animals should be specially labelled. A Japanese survey in which 80% of the sample was uncomfortable about eating bovine embryo-cloned or somatic cell-cloned beef concluded that the respondents were unfamiliar with animal cloning. It might be assumed that this lack of confidence and trust relates to a lack of understanding of cloning. Nevertheless, even after participants in the Japanese survey were provided with technological information about animal cloning, only a small proportion changed their attitudes; ~80% provided the same responses before and after receiving the information (Aizaki *et al*. 2011).

This lack of confidence and trust may be seen as an example of the 'omnivore's paradox' that highlights the contradiction for all omnivores between neophobia (a fear of new foods) and neophilia (an attraction to new foods) (Fischler 1980). For omnivores, the ability to eat a wide range of foods makes it easier to adjust to and survive in new environments; variety is also important to ensure that enough nutrients and micronutrients are supplied by the diet. Although new foods may offer particular benefits, they are potentially dangerous. The response to new technologies may be analogous, such that any modification to the familiar product – in this case beef – triggers the neophobia response and invokes suspicion and mistrust. Indeed, technology is seen as akin to 'messing' with the food; a survey of European consumers showed that the only accepted technologies were the familiar (and, implicitly, trusted) ones (Verbeke *et al*. 2010). Consumers from France, Germany, Spain and the UK showed 'severe scepticism about too much intervention in food and a strong desire to keep food and beef processing "*as simple and natural as possible*"'. They considered 'excess manipulation and distance from a "*natural*" way of processing beef products' to be very negative outcomes of technological development (Verbeke *et al*. 2010). This supports Fischler's hypothesis that the growing demand for 'natural' is a reaction against the demands faced by consumers in identifying food (Fischler 1980).

A preference for 'natural' is consistent with greater interest in the welfare and management of food-producing animals and in environmental issues associated with livestock, even though this does not necessarily translate into consumers' purchasing decisions. Celebrity chefs also draw attention to ethical and environmental qualities by endorsing particular labels, brands and certification schemes. A survey of European citizens showed that animal welfare rated eight out of 10 in terms of importance, and 62% of the sample said they would change shopping habits to access more animal welfare-friendly goods (Hartung *et al*. 2009). These consumer concerns have been recognised by animal advocacy groups that promote labelling schemes such as the Certified Human Raised and Handled label in the USA and the Humane Choice label in Australia (Francione 2012). Humane Choice, which includes free-range pastured beef in its range of labelled products, promises consumers that the animal has been treated with respect and care from birth to death and that it 'has had the best life and death offered to any farm animal' (Humane Choice 2012).

FUTURE DEVELOPMENTS

Changes in long-established patterns and models of beef consumption in recent decades warrant corresponding changes to research and greater diversification of research. With increasing world demand for beef, research into production systems will remain a high priority but other research directions will become increasingly important. Until recently, research was largely influenced by the needs and problems of producers but today's challenge is not simply to produce beef more efficiently but to produce beef that accords with current consumer values, at least in developed countries. As Hartung *et al*. (2009) noted, 'animal-friendliness' has become an additional and important quality trait for meat. The increasing relevance of environmental issues should also stimulate more research in this area; it has already been shown that emissions of methane by cattle can be reduced through nutritional management of their feed (Wyness *et al*. 2011).

REFERENCES

ABARE (2009) *Australian Commodity Statistics*. Australian Bureau of Agricultural and Resource Economics, Canberra.

ABS (2000) *Apparent Consumption of Foodstuffs Australia 1997–98 and 1998–99*. Australian Bureau of Statistics, Canberra. <http://www.abs.gov.au/ausstats/abs@.nsf/cat/4306.0> (accessed 18 February 2012).

Aizaki H, Sawada M, Sato K (2011) Consumers' attitudes towards consumption of cloned beef. The impact of exposure to technological information about animal cloning. *Appetite* **57**, 459–466. doi:10.1016/j.appet.2011.06.011.

Australian Chicken Meat Federation (2012) *Industry Facts and Figures*. <http://www.chicken.org.au>.

Barthes R (1972) *Mythologies*. Jonathan Cape, London.

Bennassar B, Goy J (1961) Consommation alimentaire (XIVe–XIXe siècle). *Annales Economies, Sociétés et Civilisations* **16**, 404–430.

Blue G (2008) If it ain't Alberta it ain't beef: local food, regional identity, (inter)national politics. *Food, Culture and Society* **11**, 69–86.

Cabrera M, Ramos A, Saadoun A, Brito G (2010) Selenium, copper, zinc iron and manganese content of seven meat cuts from Hereford and Braford steers fed pasture in Uruguay. *Meat Science* **84**, 518–528. doi:10.1016/j.meatsci.2009.10.007.

Carlson LW (2001) *Cattle: An Informal Social History*. Ivan R. Dee, Chicago.

Chalfant JA, Alston JM (1988) Accounting for changes in taste. *Journal of Political Economy* **96**, 391–410. doi:10.1086/261543.

Children's Health Development Foundation (1998) *Australian Guide to Healthy Eating: Background Information for Consumers*. Commonwealth Department for Health and Family Services, Canberra. <http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-strateg-food-resources.htm>.

Corbier M (1989) The ambiguous status of meat in ancient Rome. *Food and Foodways* **3**, 223–264. doi:10.1080/07409710.1989.9961951.

de Barcellos MD, Kügler JO, Grunert KG, Van Wezemael L, Pérez-Cueto FJA, Ueland O, Verbeke W (2011) European consumers' acceptance of beef processing technologies: a focus group study. *Innovative Food Science and Emerging Technologies* **11**, 721–732. doi:10.1016/j.ifset.2010.05.003.

Detienne M (1989) Culinary practices and the spirit of sacrifice. In *The Cuisine of Sacrifice among the Greeks*. (Eds M Detienne and J-P Vernant) pp. 1–20. University of Chicago Press, Chicago.

Ding Y, Veeman MM, Adamowicz WL (2011) Habit, BSE, and the dynamics of beef consumption. *Canadian Journal of Agricultural Economics* **59**, 337–359. doi:10.1111/j.1744-7976.2010.01205.x.

Dixon J (2002) *The Changing Chicken: Chooks, Cooks and Culinary Culture*. University of New South Wales Press, Sydney.

Edwards K (2008) Ox. *Milton Quarterly* **42**, 147–151. doi:10.1111/j.1094-348X.2008.00191_4.x.

European Institute of Oncology (2008) *Food Composition Database for Epidemiological Studies in Italy*. <http://www.ieo.it/bda2008/uk/composizione.aspx> (accessed 24 October 2011).

FAO (2009) *The State of Food and Agriculture: Livestock in the Balance*. Food and Agriculture Organization, Rome. <www.fao.org/docrep/012/i0680e/i0680e00.htm>.

FAO *Food Balance Sheets*. <http://faostat.fao.org/site/368/default.aspx#ancor>.

FAOSTAT (2011) *Food Supply*. http://faostat.fao.org/site/610/DesktopDefault.aspx?PageID=610 (accessed 24 November 2011).

FAOSTAT (2013) *Production: Cattle Meat*. <http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor>.

Fiddes N (1991) *Meat: A Natural Symbol*. Routledge, London.

Fischler C (1980) Food habits, social change and the nature/culture dilemma. *Social Sciences Information. Information Sur les Sciences Sociales* **19**, 937–953. doi:10.1177/053901848001900603.

Fischler C (1999) The 'mad cow' crisis: a global perspective. In *Food in Global History*. (Ed. R Grew) pp. 207–213. Westview, Boulder.

FranceAgriMer (2010) La consommation française de viandes: évolutions depuis 40 ans et dernières tendances. *Les Synthèses de FranceAgriMer* **1**, 1–8.

Francione GL (2012) Animal welfare, happy meat and veganism as the moral baseline. In *The Philosophy of Food*. (Ed. DM Kaplan) pp. 169–189. University of California Press, Berkeley.

FSANZ (2010) *Nuttab 2010 Online Searchable Database*. <www.foodstandards.gov.au/consumerinformation/nuttab2010>.

FSANZ (2011) Cloned animals <http://www.foodstandards.gov.au/scienceandeducation/factsheets/factsheets/cloned-animals.cfm>.

Gerrior S, Bente L, Hiza HAB (2004) The US food supply series: selected food and nutrient highlights, 2009 to 2000. *Family Economics and Nutrition Review* **16**, 57–65.

Grant M (1996) *Anthimus: De observatione ciborum. On the Observance of Foods*. Prospect Books, Blackawton, Totnes.

Harris M (1987) *The Sacred Cow and the Abominable Pig: Riddles of Food and Culture*. Touchstone/Simon and Schuster, New York.

Hartung J, Nowak B, Springorum AC (2009) Animal welfare and meat quality. In *Improving the Sensory and Nutritional Quality of Fresh Meat*. (Eds JP Kerry and D Ledward) pp. 628–646. Woodhead Publishing, Cambridge.

Horovitz R (2006) *Putting Meat on the American Table: Taste, Technology, Transformation*. Johns Hopkins University Press, Baltimore.

Humane Choice (2012) *Improving the Lives of Farm Animals and Building Consumer Confidence*. <http://www.humane-choice.com.au/>.

Kronberg SL, Scholljegerdes EJ, Lepper AN, Berg EP (2011) The effect of flaxseed supplementation on growth, carcass characteristics, fatty acid profile, retail shelf life, and sensory characteristics of beef from steers finished on grasslands of the northern Great Plains. *Journal of Animal Science* **89**, 2892–2903. doi:10.2527/jas.2011-4058.

Lamb RL, Beshear M (1998) From the plains to the plate: can the beef industry regain market share? *Economic Review Federal Reserve Bank of Kansas City* **83**, 49–66.

Lee SM, Buss DH, Holcombe GD, Hatton D (1995) Nutrient content of retail cuts of beef, pork and lamb – preliminary results. *Journal of Human Nutrition and Dietetics* **8**, 75–80. doi:10.1111/j.1365-277X.1995.tb00297.x.

Leheska JM, Thompson LD, Howe JC, Hentges E, Boyce J, Brooks JC, Shriver B, Hoover L, Miller MF (2008) Effects of conventional and grass-feeding systems on the nutrient composition of beef. *Journal of Animal Science* **86**, 3575–3585. doi:10.2527/jas.2007-0565.

Livi Bacci M (2000) *The Population of Europe: A History*. Blackwell, Oxford.

McAfee AJ, McSorley EM, Cuskelly GJ, Moss BW, Wallace JMW, Bonham MP, Fearon AM (2010) Red meat consumption: an overview of the risks and benefits. *Meat Science* **84**, 1–13. doi:10.1016/j.meatsci.2009.08.029.

Meat and Livestock Australia (2011) *Fast Facts 2011: Australia's Beef Industry*. MLA, Sydney. <http://www.mla.com.au/About-the-red-meat-industry/Industry-overview/Cattle> (accessed 1 February 2012).

Montanari M (1994) *The Culture of Food*. Blackwell, Oxford.

Muskett P (1893/1987) The Art of Living in Australia. Kangaroo Press, Sydney.

National Food Institute (2009) *Danish Food Composition Databank*. <http://www.foodcomp.dk/v7/fcdb_default.asp>.

National Food Survey (2011) *Household Consumption of Selected Foods from 1942 to 2000*. <http://www.defra.gov.uk/statistics/foodfarm/food/familyfood/nationalfoodsurvey> (accessed 25 January 2012).

Nicklas T, O'Neil C, Zanovec M, Keast D, Fulgoni V III (2012) Contribution of beef consumption to nutrient intake, diet quality, and food patterns in the diets of the US population. *Meat Science* **90**, 152–158. doi:10.1016/j.meatsci.2011.06.021.

Nutrition Fact Sheet (2003) Beef: nutrients that work as hard as you do. *Journal of the American Dietetic Association* **103**, 408–409.

O'Neil C, Zanovec M, Keast DR, Fulgoni VL, Nicklas TA (2011) Nutrient contribution of total and lean beef in diets of US children and adolescents: National Health and Nutrition Examination Survey 1999–2004. *Meat Science* **87**, 250–256. doi:10.1016/j.meatsci.2010.10.020.

Oddy DJ (1970) Working-class diets in late nineteenth-century Britain. *Economic History Review* **23**, 314–323. doi:10.2307/2593832.

Parsonson I (1998) *The Australian Ark*. CSIRO Publishing, Melbourne.

Ponnampalam EN, Mann NJ, Sinclair AJ (2006) Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and trans fatty acids in Australian beef cuts: potential impact on human health. *Asia Pacific Journal of Clinical Nutrition* **15**, 21–29.

Prynne CJ, Wagemakers JJMF, Stephen AM, Wadsworth MEJ (2009) Meat consumption after disaggregation of meat dishes in a cohort of British adults in 1989 and 1999 in relation to diet quality. *European Journal of Clinical Nutrition* **63**, 660–666. doi:10.1038/ejcn.2008.7.

Rifkin J (1992) *Beyond Beef: The Rise and Fall of the Cattle Culture*. Penguin, New York.

Rimas A, Fraser EDG (2008) *Beef: The Untold Story of How Milk, Meat and Muscle Shaped the World*. HarperCollins, New York.

Rogers B (2003) *Beef and Liberty*. Chatto and Windus, London.

Roussell M, Kris-Etherton P (2012) Reply to AM Bernstein and WC Willett. *American Journal of Clinical Nutrition* **95**, 1295–1296. doi:10.3945/ajcn.112.034389.

Santich B (1988) Two languages, two cultures, two cuisines: a comparative study of the culinary cultures of northern and southern France, Italy and Catalonia in the fourteenth and fifteenth centuries. PhD thesis. Flinders University, Adelaide.

Santich B (1995) *What the Doctors Ordered: 150 Years of Dietary Advice in Australia*. Hyland House, Melbourne.

Schlenker W, Villas-Boas SB (2009) Consumer and market responses to mad cow disease. *American Journal of Agricultural Economics* **91**, 1140–1152. doi:10.1111/j.1467-8276.2009.01315.x.

Schlosser E (2001) *Fast Food Nation: The Dark Side of the All-American Meal*. Houghton Mifflin, Boston.

Simopoulos AP (2002) The importance of the ratio of omega-6/omega-3 essential fatty acids. *Biomedicine and Pharmacotherapy* **56**, 365–379. doi:10.1016/S0753-3322(02)00253-6.

Smith A (2008) *Hamburger: A Global History*. Reaktion Books, London.

Stouff L (1970) *Ravitaillement et Alimentation en Provence au XIV et XV Siècles*. Mouton et Co., Paris.

Thompson H (1901) *Food and Feeding*. 11th edn. Frederick Warne and Co., London.

Tonsor GT, Olynk NJ (2011) Impacts of animal well-being and welfare media on meat demand. *Journal of Agricultural Economics* **62**, 59–72. doi:10.1111/j.1477-9552.2010.00266.x.

Troy DJ, Kerry JP (2010) Consumer perception and the role of science in the meat industry. *Meat Science* **86**, 214–226. doi:10.1016/j.meatsci.2010.05.009.

Umberger WJ, Boxall PC, Lacy RC (2009) Role of credence and health information in determining US consumers' willingness-to-pay for grass-finished beef. *Australian Journal of Agricultural and Resource Economics* **53**, 602–623.

USDA (2011) *Livestock and Poultry: World Markets and Trade, October 2011*. <www.fas.usda.gov/livestock_arc.asp> (accessed 22 January 2012).

USDA *National Nutrient Database for Standard Reference*. <http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl>.

USDA (2001–2002) Profiling food consumption in America. In *Agriculture Fact Book*. <http://www.usda.gov/factbook/chapter2.pdf> (accessed 15 November 2011).

USDA Economic Research Service (2011) *Food Availability Spreadsheets*. <www.ers.usda.gov/data/foodconsumption/FoodAvailspreadsheets.htm> (accessed 17 February 2012).

USDA Foreign Agricultural Service (2011) *Livestock and Poultry: World Markets and Trade*. www.fas.usda.gov/dlp/circular/2011/livestock_poultry.pdf.

Van Wezemael L, Verbeke M, de Barcellos MD, Scholderer J, Perez-Cueto F (2010) Consumer perceptions of beef healthiness: results from a qualitative study in four European countries. *BMC Public Health* **10**, 342–351. doi:10.1186/1471-2458-10-342.

Velten H (2007) *Cow*. Reaktion Books, London.

Verbeke W, Pérez-Cueto FJA, de Barcellos M, Krystallis A, Grunert KG (2010) European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science* **84**, 284–292. doi:10.1016/j.meatsci.2009.05.001.

Williams P (2007) Nutritional composition of red meat, Section 2: key nutrients delivered by red meat in the diet. *Nutrition and Dietetics* **64**, S113–S119. doi:10.1111/j.1747-0080.2007.00197.x.

Williams P, Droulez V (2010) Australian red meat consumption: implications of changes over 20 years on nutrient composition. *Food Australia* **6**, 87–94.

Williams P, Droulez V, Levy G, Stobaus T (2007) Composition of Australian red meat 2002. 3. Nutrient profile. *Food Australia* **59**, 331–341.

Wilson CA (1973) *Food and Drink in Britain: From the Stone Age to Recent Times*. Constable, London.

World Bank (2013) *GNI per capita, PPP (current international $).* <http://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD>.

Wyness L, Weichselbaum E, O'Connor A, Williams EB, Benelam B, Riley H, Stanner S (2011) Red meat in the diet: an update. *Nutrition Bulletin* **36**, 34–77. doi:10.1111/j.1467-3010.2010.01871.x.

Zanovec M, O'Neil C, Keast D, Fulgoni V III, Nicklas T (2010) Lean beef contributes significant amounts of key nutrients to the diets of US adults: National Health and Nutrition Examination Survey 1999–2004. *Nutrition Research* **30**, 375–381. doi:10.1016/j.nutres.2010.06.001.

2 Beef processing and carcass and meat quality

D.L. Hopkins

INTRODUCTION

A key outcome of the beef industry is the production of meat to satisfy the many markets that Australia services around the world. The type of product varies according to the market, from the expensive highly marbled beef sought after in Japan to the large demand for grinding meat in the USA to service the fast food industry. In all cases there are optimal carcass types and the Australian processing industry has adopted some of the latest approaches to slaughter, boning and product handling. Continual cost pressure will require the industry to adopt less labour-intensive processes and increasing the return per carcass will be required through maximising compliance to specifications and further value-adding and utilisation of the whole carcass.

PRE-SLAUGHTER HANDLING AND LAIRAGE

Cattle pass through a series of phases on their way from a farm to an abattoir. Commonly, these phases include 1) farm curfew without access to feed and water, 2) saleyards and 3) abattoir with transportation required for the delivery of cattle to the latter two phases. Some animals are sold directly to abattoirs, thus avoiding the saleyard and dual transport journeys. All slaughter animals spend time in lairage (i.e. resting) at abattoirs; this time period varies depending on processor numbers and the order of slaughter.

The purpose of farm curfew is to prepare livestock for transport and, specifically, to reduce the volume of material in the gastrointestinal tract and urinary bladder before transport. Some abattoirs will accept short curfew times and the commensurate increase in excreta. During the phases from farm to abattoir, animals are exposed to various stimuli outlined by Ferguson and Warner (2008):

1. handling and increased human contact;
2. transport;
3. novel/unfamiliar environments;
4. food and water deprivation;
5. changes in social structure;
6. variation in climatic conditions.

FASTING

The stimuli listed above can collectively and separately have negative effects on carcass and meat quality. Weight loss is inevitable due to feed and water deprivation before, during or after transportation. Under Australian conditions that include long transport distances and elevated summer temperatures, these effects can be exacerbated. For example, cattle transported 70 km and fasted (no feed or water) for 60 h lost 12% of their initial liveweight (Wythes *et al*. 1981a) compared to only 4% in cattle experiencing the same treatment for 12 h. Extended periods of transport and lairage will increase the loss of carcass weight (Wythes *et al*. 1981b), which represents an economic loss. Such losses in weight decrease exponentially with time off feed and water (Shorthose and Wythes 1988). Reductions in carcass weight of up to 0.5% per day on average from transport and fasting, have been reported (Shorthose and Wythes 1988), with other estimates being up to a total of 8% in lost carcass weight (Warriss 1990) depending on the duration of fasting and transport. Other body components (liver, skin etc.) also exhibit weight loss as the time off feed and/or water is extended. Furthermore, fasted animals will exhibit gluconeogenesis and fat mobilisation to maintain energetic homeostasis and this could lead to changes in meat quality, such as elevated pH.

Dehydration can cause stress with a significant impact on meat colour and shelf life. Cortisol released from the adrenal glands during stress has a diuretic effect (i.e. increases water loss by the kidneys) and may simultaneously depress water intake. In lairage at abattoirs, cattle have access to water, hence an opportunity for rehydration, but this is dependent on them drinking in unfamiliar surroundings. Codes of practice for animal welfare at abattoirs have specific recommendations for supplying water to cattle (Anonymous 2002b). Current Australian codes for the transport of cattle specify a maximum period of 48 h between the provision of water at the start and end of a journey for cattle over six months of age (Anonymous 2012). An important consequence of fasting is the elevated growth of *E. coli* in the rumen (Brownlie and Grau 1967); Hogan *et al.* (2007) proposed this could reflect a reduction in fermentable carbohydrate forcing pathogenic microbes to compete for energy. It has been shown that feeding hay for 48 h before transport to an abattoir reduces the level of bacteria like *E. coli* (Gregory *et al.* 2000) in the digesta, compared to fasted or pasture-fed cattle. However, the reduction in energy intake, from hay-based diets that may have a lower energy content than pasture, could lead to lower muscle glycogen levels and thus higher pH meat. As such, the provision of high-quality hay would be required for this to be a useful strategy. Animals conserve water in response to water deprivation by increasing the concentration of urine, which can be indicated by measurement of urine-specific gravity. Overall, short lairage times and limited fasting are considered best practice.

Stress effects

Animals faced with stressful situations will have an altered metabolism dependent on the type of stress (Ferguson and Warner 2008). This can lead to significant depletion of muscle glycogen (Warriss 1990); if the level falls to 45–57 mmol/kg then a ‘normal’ ultimate pH will not be reached when the animal is slaughtered (Tarrant 1989). This will lead to reduced keeping quality (Egan and Shay 1988), increases in toughness specifically up to about pH 6.0 (Bouton *et al.* 1973a; Purchas *et al.* 1999) and darker meat (Truscott 1988). Beef with a high pH is often referred to as dark, firm and dry (DFD), but the critical pH threshold for DFD is not clear. Some researchers refer to meat with a pH above 5.9 (Ferguson *et al.* 2001) as DFD, whereas others (McGilchrist *et al.* 2011) applied a pH of 5.7 and above as DFD, yet others used a pH of 6.0 and above (Apple *et al.* 2006). The latter threshold is in some ways the most appropriate for muscle structure as it shows more dramatic changes when the pH exceeds 6.0 with increased water-holding capacity (Huff-Lonergan and Lonergan 2005) and off-flavours. Meat buyers tend to discriminate on a colour basis above a pH of 5.8–5.9 (Truscott 1988).

The level of DFD meat in the beef industry indicates that it can be a significant problem with Australian work reporting a mean incidence of 9.6% using a pH threshold of 5.8 and 4% with a threshold of 6.0, but with up to 16% of carcasses falling into the DFD classification (Warner *et al.* 1988). In this study the incidence was reduced if cattle spent less time in lairage and if they came from feedlots. More recent work has shown levels of DFD up to 18% using a pH threshold of 5.7 in cattle fed for ~150 days in a feedlot (Hopkins *et al.* 2007) and up to 22% in cattle less than 350 kg carcass weight (McGilchrist *et al.* 2012). In this case, the level of DFD in winter was significantly higher than in autumn. It has been reported that faster-growing cattle are at less risk of producing high pH meat (Smith *et al.* 1999). This could be due to slower-growing cattle having lower muscle glycogen levels, but they may also be more stress sensitive. For example, as flight speed increased from 0.75 to 2.25 m/s muscle glycogen concentration decreased by 8.9% (McGilchrist *et al.* 2011). However, more agitated behaviour doesn’t always translate into a higher pH (Fordyce *et al.* 1988; Petherick *et al.* 2002), but it has been reported to lead to higher levels of dark meat (Voisinet *et al.* 1997). There have also been reports that more agitated behaviour leads to tougher meat when measured by shear force (Fordyce *et al.* 1988; Voisinet *et al.* 1997). Others have reported no correlation between flight speed and eating quality as assessed by Meat Standards Australia (MSA) protocols (Petherick *et al.* 2002) or a low correlation between temperament scores, flight speed and shear force (King *et al.* 2006). More recently, Cafe *et al.* (2011) showed that a higher flight speed score did lead to an increase in shear force and pH, with some decrease in the lightness of meat colour, but the effects were influenced by breed of cattle and production region of the cattle.

Aside from an impact on meat colour and tenderness, the stressful effects of transport, handling and lairage can impact on the general well-being of cattle, with practices like loading cattle being more stressful than unloading (Fisher *et al.* 2009). Temperament and genetic effects also affect the response of cattle to stressful situations, as can the mixing of unfamiliar cattle during lairage; bulls are the most susceptible. As a result, MSA does not allow mixing of cattle two weeks before slaughter (Colditz *et al.* 2006). To produce high-quality beef, attention needs to be given to nutritional management and handling of cattle pre-slaughter, with handling and long lairage periods being minimised or avoided. According to Fisher *et al.* (2009), the benefits of resting animals that have been transported long distances is equivocal.

Another important consideration for managing stress levels of cattle is treatment at the abattoir. The application of electric prodders to cattle six times in the 15 min before slaughter reduced eating quality by 4 points (on a 100 point scale) and increased fluid loss from the muscle compared to cattle not prodded (Warner *et al.* 2007). However, in this study there was no impact on pH, shear force or meat colour. The use of electric prods has been shown to raise cortisol levels (Hemsworth *et al.* 2011).

MSA recommendations for pre-slaughter handling and treatment of cattle (Anonymous 2010a) with additions from the relevant code (Anonymous 2002b) are given in Table 2.1.

A practical yet important method for reducing pre-slaughter stress is the use of animal handling facilities and principles that account for animal behaviour (Chapter 13). Grandin (1993) and Barton Gade (2004) provide a good overview of the critical considerations to reduce pre-slaughter stress and improve animal welfare. For example, circular yard design facilitates movement of cattle as it recognises the natural herding and movement habits of cattle. Races should have solid sides leading to the stunning area of an abattoir (Grandin 1993; Fig. 2.1) and be well lit (Grandin 2001). Gateways should be wide with no protruding fittings and loading ramps should have non-slip bases and inclines of less than 1 in 3 (20°). As outlined by Grandin (1993), the degree of vocalisation of cattle can be used to assess the functionality of lairage design as vocalisation is correlated with physiological measures of stress (Hemsworth *et al.* 2011). Further suggestions for streamlining the transfer of cattle into the knocking box are given by Grandin (2010, 2011).

Table 2.1: Recommendations for the production of high-quality beef

Location	
On farm/ transport	Cattle must be fed adequate nutrition to ensure growth (at least 0.9 kg/day) for a minimum of one month before slaughter Cattle must have access to water until transportation and be handled quietly to reduce stress Cattle with a flighty temperament are not to be transported, nor are sick cattle Don't mix groups of unfamiliar animals Minimal use of goads or electric prodders Transport cattle at the recommended densities as per the trucking industry code of practice
Abattoir	Adequate fresh water for all cattle so that all animals can drink within 1 h of arrival at the abattoir If cattle are held for more then 24 h then feed must be provided to maintain liveweight Provision of shade Well-designed lairage that accounts for cattle behaviour

Figure 2.1: Ramp with closed sides leading to the slaughter point. Source: CSIRO Food and Nutritional Sciences.

Management pre-slaughter

Agitated cattle with poor temperament exhibit higher levels of carcass bruising, particularly in the back and hip regions (Fordyce *et al.* 1988). This has a direct economic consequence for producers and processors, with recorded losses of up to 1.5 kg of meat per carcass. Docile cattle lose less weight during transport and recover weight more quickly while resting after transport (Colditz *et al.* 2006). There is further evidence that breed type has an impact on stress responsiveness (Muchenje *et al.* 2009; Cafe *et al.* 2011). Therefore, selection emphasis on improving temperament on farm will have tangible benefits to the cattle industry. Available evidence indicates that there is a desirable genetic relationship between temperament and meat shear force (Reverter *et al*. 2003).

The use of dietary supplements as a means of limiting the impact of pre-slaughter transport and handling on meat quality has been investigated. This includes supplementation with electrolytes and/or carbohydrates such as glucose (Schaefer *et al*. 1990), given that cattle can experience dehydration, electrolyte imbalance and hypoglycaemia when transported and held in lairage before slaughter. Periods without feed and water in bulls have been shown to decrease eating quality if the period reached 36 h before slaughter (Jeremiah *et al*. 1992), thus highlighting the importance of the pre-slaughter handling. Interestingly, the early work of Schaefer *et al*. (1990) reported an increase in carcass weight of 3.0% in cattle given either electrolytes or glucose compared to cattle given only water or no water while in lairage, but there was no clear positive effect on meat colour, shear force or pH. Later work by Schaefer *et al*. (1992) confirmed the improvement in carcass weight from the supply of electrolytes. In this work, urinary sodium levels and osmolality were decreased in treated cattle, indicative of a higher fluid intake which was reflected in heavier carcass weights. This Canadian work led to a registered product Nutricharge®. Some Australian work showed no benefit in reducing liveweight loss from the use of this product during transportation, but the diet fed pre-transport which contained cottonseed meal and molasses may have nullified any benefits (Colditz *et al*. 2006). Apart from a direct effect, it is possible that supplements could encourage cattle to drink more water while in lairage and this would have a beneficial effect on maintaining hydration.

The report of Jeremiah *et al*. (1992) indicated that the use of electrolytes in bulls led to a decrease in overall palatability of the meat, but no explanation was given for this. It is unclear whether a rise in electrolytes would translate into a direct effect on palatability, as meat enhancement with salt-based solutions gives equivocal results in which effects are impacted by the muscle/cut under study (Stetzer *et al*. 2008).

Another supplement that has been studied for its effects on meat quality in other species is magnesium. Magnesium has been shown to depress neuromuscular stimulation, thus inducing a relaxant effect, but there do not appear to be studies on the usefulness of this supplement for cattle. Another compound which has not been studied for its effect on alleviating weight loss in cattle is betaine, which acts as an organic osmolyte in plants, although a study in lambs showed no benefit from feeding betaine pre-slaughter (Pearce *et al*. 2008).

The level of nutrition pre-slaughter impacts on growth rate and this production indicator can consequently affect traits like palatability; however, the literature is not in agreement on the importance of growth rate on palatability (Thompson 2002). In the Australian-developed MSA meat grading system, carcass weight in relation to ossification score is incorporated into the prediction model (Watson *et al*. 2008) so this would account for growth rate differences. Growth rate pre-slaughter will impact on muscle glycogen levels as outlined above, and thus on pH, so higher growth rates are desirable.

SLAUGHTER PROCESS

The knocking box is the most common method of restraining cattle for stunning and is often used with a head restraint. Regulations require that animals be humanely killed (i.e. stunned with either a captive bolt or electrically, meaning they are rendered insensible to pain: Grandin 1993) and are unconscious during bleeding.

Stunning

The most common type of stunning of cattle is captive bolt (Fig. 2.2), although electrical stunning is becoming more widespread due to concerns about the spread of bovine spongiform encephalopathy (BSE) prions from the brain to edible tissue (Gregory 2005). Captive bolt systems are either cartridge or pneumatically powered. With the captive bolt, a state of concussion is induced and if the bolt does not cause excessive tissue damage, the animal can regain consciousness (Wotton *et al*. 2000). The correct frontal target area for effective captive bolt stunning corresponds to the intersection of two lines which cross between the eyes and the upper portion of the ears with reference to the middle of the head.

The following criteria must be achieved for an effective stun using a captive bolt:

- collapse of the animal;
- no corneal reflex;
- eye balls not rotated;
- absence of normal rhythmic breathing.

After a successful stun, tonic spasms with some clonic activity (kicking) normally follow. Research has shown that bulls require more than one shot to produce an equally effective stun compared to steers or heifers (Gregory *et al*. 2007), indicating that a more powerful shot is warranted for bulls. Soft-sounding shots should alert operators to the likelihood of a poor depth of concussion.

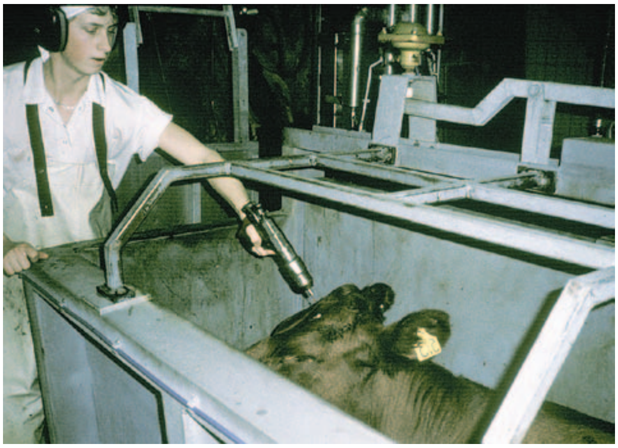


Figure 2.2: Head-stunning a beast with a captive bolt. Source: N.G. Gregory.

The power of a stun has been shown to affect the level of hormones, with high-powered captive bolt inducing higher levels of adrenalin and ACTH (Anonymous 2011a), with flow-on negative effects for meat quality. Thus a careful balance is required between the power of the stun and the effectiveness of the stun. Cartridges in captive bolts vary in strength and are classified according to the amount of propellant they contain, measured in grains, with 4 grains being required for large cattle. Auditing of the stunning process has shown that up to 95% of cattle can be effectively stunned on the first shot (Grandin 2010).

During electrical stunning the animal becomes rigid as neurotransmitters are released (Cook *et al.* 1996) within the brain, leading to an epileptic-like seizure. The stunner must have sufficient current through the brain to induce the seizure (*grand mal*). The minimum current required for an effective stun is 1.2 A, and 1.5 A to fibrillate the heart at 550 V and 50 Hz (Wotton *et al.* 2000). This particular stunner runs three cycles: 1) head-only cycle, 2) cardiac cycle to induce ventricular fibrillation, and 3) a spinal discharge cycle to reduce convulsions after death.

Following an effective electric stun there are three phases:

- a tonic phase characterised by rigidity due to the release of glutamate;
- a clonic phase characterised by paddling or involuntary kicking;
- a recovery phase during which normal rhythmic breathing starts again (this phase will not occur during normal abattoir procedures).

If kicking occurs immediately after applying the current, this indicates that the stun was probably not totally effective. However, physical movement cannot be relied upon to conclusively indicate the effectiveness of the stun. Absence of normal rhythmic breathing and lack of eye reflexes are better indicators. If only head stunning is used to satisfy halal requirements, then exsanguination or sticking needs to occur as soon as possible after stunning. In a head-only stun, the current passes through the brain and the animal recovers unless exsanguination occurs within 35–45 s of the stun (Lambooji 2004). Combining head-only stunning and exsanguination increases the duration of unconsciousness via the release of glutamate and aspartate. Electrical stunning is widely practised around the world. An electroencephalography (EEG) is used to show brain response to stunning and demonstrate interruption to electrical activity of the brain (Fig. 2.3a) and the corresponding uninterrupted pattern from an effective stun (Fig. 2.3b).

Exsanguination should occur before reflex kicking begins and the sooner after stunning the better, to reduce blood splash (ecchymosis). Blood splash is the escape of blood from blood vessels into muscle tissue; these haemorrhages appear as dark red spots (Fig. 2.4) on meat cuts. The exact cause is not known, although it appears to arise from high blood pressure and possibly weak blood vessels. Gregory (2005) gave four explanations of why blood splash occurs with electrical stunning: 1) pre-slaughter stress may predispose cattle to blood splash by elevating blood pressure, 2) ineffective stunning can also lead to higher blood pressure, 3) blood vessels experience severe external pressure due to muscle contractions (Lambooji 2004) and 4) hot weather can increase the incidence of blood splash.

Stunning equipment should be checked to ensure that it is delivering the appropriate current or voltage according to the manufacturer's guidelines. Most commonly an alternating current at a frequency of 50 Hz with a sinusoidal waveform is used for stunning (Wotton *et al.* 2000), but much higher frequencies up to 1800 Hz have been used (Lambooji 2004) as a means of reducing any direct muscle stimulation and thus contraction. At higher frequencies, the wavelength is shortened and thus neurons are discharged more often. This 'exhaustion' means the muscle cannot keep responding to the external current, whereas the nervous system has a much higher threshold. This should limit the occurrence of ecchymosis. Decarbonising the electrodes regularly with a wire brush will help to ensure good contact with the head of the animal. In Fig. 2.5 the nose of the animal rests on the electrode plate and there is another electrode as part of the head crush.

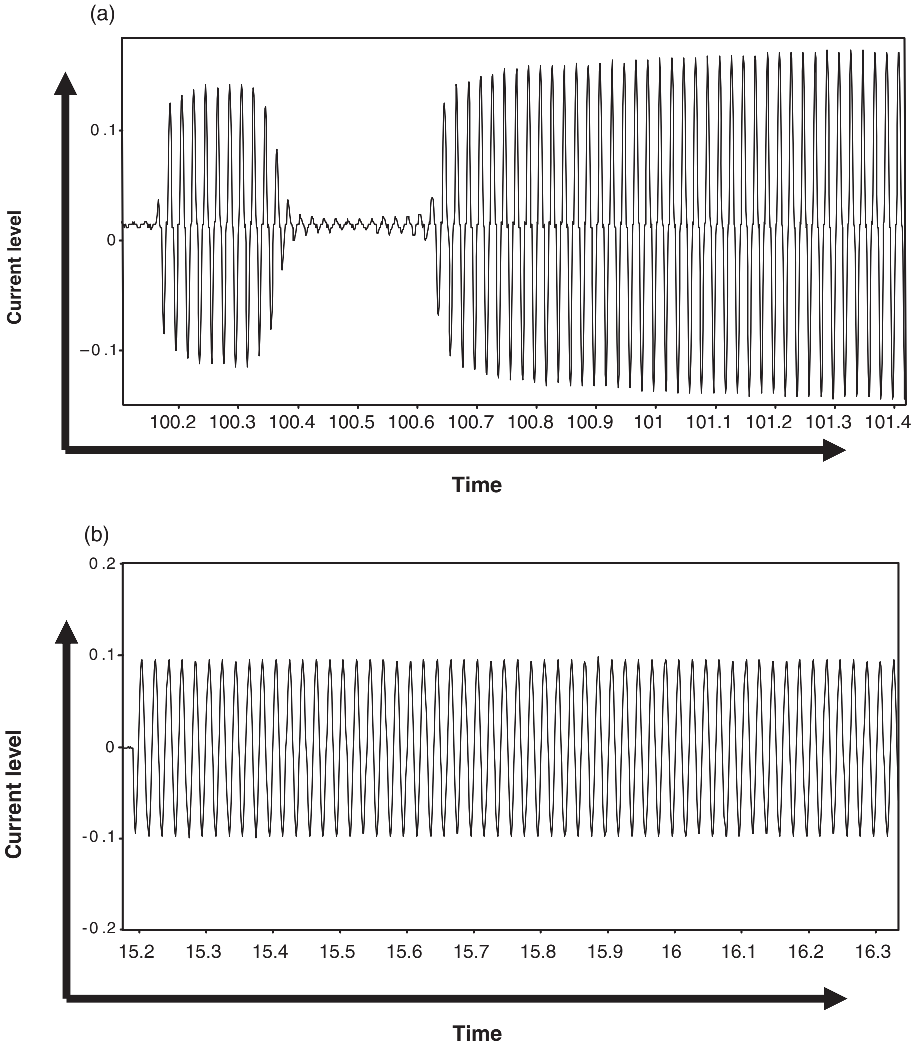


Figure 2.3: (a) EEG trace for an interrupted stun. (b) EEG trace for an effective stun. Source: CSIRO Food and Nutritional Sciences.

For stunning systems that apply head-to-body cycles which result in cardiac arrest and inactivation of the spinal nervous system, the time to sticking is less critical. For these reasons a head-to-body stunner is a safer alternative because it leads to minimal animal movement. Using this system, sticking must be undertaken to ensure proper bleeding (thoracic stick – severing the vena cava and the aorta). Electrode placement is critical to ensure cardiac arrest and the heart must be spanned. The application sites can be wetted to ensure proper electrical contact; this also lessens skin burns.

Head-to-body stunners do reduce blood splash because of a reduction in blood pressure, but are not acceptable for halal (Islamic) slaughter. A single cut severing the carotid arteries, jugular veins, trachea and oesophagus must be executed for halal slaughter, in conjunction with head-only stunning. The halal slaughter process requires the first penetration of the body to be the slaughter man's knife, and he must be

Figure 2.4: Cut showing extensive blood splash, as dark spots. Source: CSIRO Food and Nutritional Sciences.

Figure 2.5: Application of electrical stunning to a cow. Source: C.E. Devine.

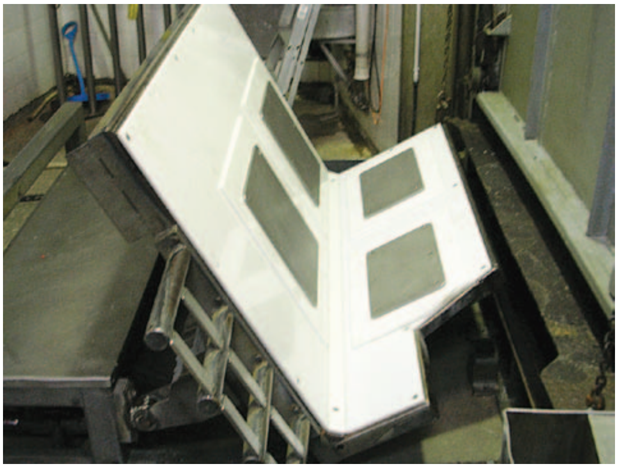


Figure 2.6: Immobilisation unit used immediately post stunning and before the carcasses are placed on the chain. The electrodes are clearly seen. Source: I.J. Richards.

specially trained and accredited. A prayer is said for each animal. For a kosher (Jewish) slaughter, the animals must be fully conscious and the throat must be cut with one rapid continuous motion. More detail on these methods is given by Shragge and Price (2004). Thoracic sticking, whereby the brachiocephalic trunk near the heart is severed, has been shown to increase the amount of blood drained from the body soon after sticking (Anonymous 2011a) and to reduce carotid occlusion. There are also electrical approaches after sticking which can be used to increase blood collection during early stages of the slaughter process.

Immobilisation

Early work in New Zealand showed that head-only stunning of cattle could be combined with exsanguination, and then electrical immobilisation to ensure insensibility and stillness (Devine *et al.* 1986). Immobilisation was applied 20 s after stunning and involved application of 80 V, 14.3 Hz, 300 mA of electricity for 30–37 s via electrodes connected to the nose and anus. This approach reduced animal movement and allowed safe dressing of the carcass. More recently, new immobilisation systems have been developed in Australia with a constant current applied while the animal is in the knocking box after stunning, or after the animal is exited from the knocking box onto a V-bed (Fig. 2.6). The principle of these systems has been the use of high frequencies, e.g. up to 2000 Hz, current 1–2 A with a pulse width of 0.15 ms applied for up to 15 s. This has been shown to be very effective at reducing animal movement immediately after stunning, allowing safe shackling and exsanguination, thus reducing the risk of knife injuries due to reflex movements. Evidence indicates that this application does not have any detrimental effect on meat quality, particularly pH (Anonymous 2006a), thus enabling other electrical inputs further down the slaughter chain to be applied to either enhance bleeding or the rate of pH decline.

Electronic bleeding

With normal processing procedures, cattle are held in a bleeding area to maximise the collection of blood and reduce the biological oxygen demand (BOD) of the effluent collected from washdown activities further along the chain. New electrical systems based on medium voltage, with a square pulse of short duration (Devine *et al.* 2004), have the potential to include systems to assist bleeding as they do not require isolation from abattoir workers and can be retrofitted into existing slaughter floors more easily. Limited data suggests that at least an extra 1 kg of blood could be collected per animal from the exposure of carcasses within 2 min of sticking to electricity at either 5 or 14 Hz and 500 mA (Anonymous 2006a). This response has been verified by work in sheep (Hopkins *et al.* 2006). In the case of the cattle system, the pulse interval is commonly 200 msecs with a pulse width of 500 µsecs. Since the 5 Hz frequency has less impact on muscle pH (Anonymous 2006a) this is used where minimal stimulation effects are desired, although it has been observed that these parameters may still produce a stimulation effect. A typical system (Fig. 2.7) has the current administered through the hind legs; in this case the electrical parameters were 5 Hz, constant current of 500 mA and a pulse width of 200 msecs. For abattoirs that sell blood meal, there are improved profits from applying

Figure 2.7: Electronic bleeding unit used immediately post stunning and before the carcasses are dressed. The electrodes operate through the hind leg as shown. Source: I.J. Richards.

Figure 2.8: Robotic hock cutter. Source: Machinery Automation & Robotics.

this approach. More blood collected in the bleeding area reduces the amount of blood present on the floor beneath the processing chain, the amount of blood that enters effluent (thus decreasing the BOD of the effluent) and the amount of water required to hose the blood away.

Pelt removal and dressing

After hoisting onto the chain, cattle dressing can commence with removal of the hide first from around the free hind leg. In some cases, particularly with feedlot cattle, dags (i.e. manure deposits) may need to be removed to reduce bacterial contamination; several de-dagging devices have been designed, with limited success. Many abattoirs would use a steam vacuum system to remove contamination during dressing. A detailed description of the dressing procedure is given by Belk and Scanga (2004). It should be noted that the front lower limbs are usually removed at the junction of the proximal and distal carpal bones, often with the aid of hock cutters. This procedure has now been mechanised in some abattoirs with robotic hock cutters (Fig. 2.8).

The hide is removed completely from the carcass using either upward or downward pullers. A critical component of this step is the use of back stiffeners. These have probes that are forced into the carcass (Fig. 2.9) and an electrical current is applied to the carcass. This approach is used in downward hide pullers and is designed to prevent broken backs from the force which is applied to the carcass as the hide is removed from the lower part of the carcass, by causing the carcass to become stiff. The currents for such probes could be 3 A at 50 Hz (Anonymous 2006a), and such probes have been found to increase the decline in muscle pH with variable times of application in the same abattoir typically from 7–16 s (Warner 2010). In cases where minimal impacts on the rate of pH decline are desired, new pulse energy back stiffeners have been developed in Australia which use only contact plates rather than penetrating probes. These units deliver a pulsed waveform (i.e. inverse exponential as opposed to a

Figure 2.9: Rigidity probe in combination with a downward hide puller. Source: CSIRO Food and Nutritional Sciences.

common sine wave) at 40 Hz and 375 peak voltage with a pulse width dependent on load resistance. Strict control over the length of application can reduce the effect on the rate of pH decline.

The quality of dressing has a significant impact on the final value of skins and particular attention needs to be paid to knife cuts during pelt removal. Cuts reduce the value of the resultant leather, making the skins unusable as mats and often causing the skin to tear during tanning. Flay marks are less obvious but result in thin, weak areas.

Evisceration

After pelt and hock removal, evisceration presents the major labour requirement of the cattle slaughtering system. The first step is to separate the oesophagus and the trachea (weasand), which is done with a 'weasand' rod, and the oesophagus is tied off to prevent leakage from the digestive tract. Following this, brisket splitting is undertaken, a process often mechanised by the use of a blunt end cutter to prevent the blade from rupturing the rumen. During evisceration, the stomach, liver, spleen, lungs and heart are removed. The last major activity is the splitting of the carcass laterally down through the spine (Fig. 2.10). Given concerns over BSE, the spinal cords are removed from carcasses, sometimes with the aid of vacuum-based systems. There are robotic systems under development for splitting carcasses.

MEAT INSPECTION

Ante mortem (before death) inspection is usually carried out in the lairage on the morning of slaughter. The inspector looks for symptoms of any zoonotically transmissible diseases to humans or other animals that will automatically render the meat unfit for consumption. The qualifications of such inspectors vary between and within countries depending on the local regulations. No animals appearing to suffer from such a disease should be slaughtered for human consumption. Regulations vary according to country (e.g. for Australia, see Anonymous 2007a).

Figure 2.10: Carcass splitting using a saw with an endless blade. Source: D.L. Hopkins.

During slaughter and after the removal of the skin, the gastrointestinal tract and internal organs and the carcass are inspected for signs of disease (e.g. cattle worms, jaundice, arthritis, pneumonia; Chapter 13) and the contamination of carcasses is also assessed. If bruising or lesions are detected on the carcass they are trimmed. In some cases, tissue samples are taken for chemical residue testing, with maximum residue levels applying to specific chemicals. Carcasses are commonly washed after evisceration and splitting either by hand or by passing through automatic wash stations; however, hide on washers have also been used to reduce bacterial contamination (Arthur *et al.* 2010).

A major consideration is the reduction of bacterial contamination, and good hygiene systems are required to limit the transfer of bacteria from the skin, faeces and humans to the carcass. The bacteria of concern for fresh meat are *Salmonella* spp., *E. coli* and *Campylobacter* spp. (Sofos 2008). It has been shown that *Campylobacter* is the most common food-borne pathogen of humans in several countries (Vanselow *et al.* 2007). Although feed withdrawal may reduce the load in the gastrointestinal tract and the bladder, there is some evidence that it may increase the level of bacteria such as *E. coli*, based on cattle studies (Gregory *et al.* 2000). Recent investigation has identified that a proportion of cattle harbour high levels of *E. coli* including the deadly 0157:H7 strain; these cattle have been termed 'super shedders' (Arthur *et al.* 2010).

A logical and systematic approach to reducing contamination involves the identification of hazards, establishing the level of risk, identifying points where control can be implemented, selection of control options and monitoring the control. This approach is termed Hazard Analysis Critical Control Points (HACCP). There are several control options to reduce contamination levels: 1) hot water ≥80°C must be used to decontaminate knives and viscera inspection systems, 2) trimming visible contamination, 3) steam vacuuming (Rekow *et al.* 2011) and 4) washing with water (Koutsoumanis and Sofos 2004). Hot water washes are more effective at reducing bacterial load (Sheridan 1998) and some abattoirs overseas use commercial dehairing to reduce contamination using sodium sulphide and hydrogen peroxide.

CARCASS MEASUREMENT AND YIELD ESTIMATION

Methods of measurement

There is no international carcass grading or measurement system for beef carcasses. The systems that do exist are based on subjective assessments of fat cover and conformation or on objective measures taken on the carcass. The European Union takes the first approach (de Boer 1992). It uses five conformation classes (EUROP) with 'E' being the best conformed and 'P' the least. Countries have the option of including an 'S' class for carcasses with very superior conformation (Allen 2009). There are five fat classes (1–5) in the European system, with 5 being the fattest, and subdivisions within classes into high and low levels are used by some countries. In the USA, there is an option to give one of five yield grades (YG) to beef carcasses based on carcass weight, subcutaneous fat thickness at the 12th rib, *longissimus* cross-sectional area at the 12th rib (EMA) and the percent of kidney, pelvic and heart fat (Anonymous 1988), with YG1 having the highest yield grade and YG5 the lowest.

In Australia, early work (Anonymous 1981) was designed to classify carcasses according to sex, age, subcutaneous fat thickness and carcass weight, but this moved to carcasses being described by specifications instead of rigid classes. This approach relied on the measurement of subcutaneous fat thickness at the 12th rib and a manual system was developed using a 'cut and measure' knife (Fig. 2.11 shows where the fat depth was measured). The use of the rib site for measuring fat depth was questioned, with claims that damage due to hide pullers was greater at the 12th rib site than at a site on the sacral crest (Johnson and Vidyadaran 1981) such that up to 20% of carcasses couldn't be measured due to removal of fat at the 12th rib.

Figure 2.11: Site for the measurement of subcutaneous fat depth. Source: J. House.

Removal of fat from the 12th rib was shown not to hold universally across Australia (Hopkins 1989a), with differences between abattoirs due to the degree of care given to the dressing procedure. Nevertheless, the measurement site was changed to what is called the P8 rump site. This site is defined as the point of intersection of a vertical line from the dorsal tuberosity of the tripartite tuber ischii parallel with the chine, and a horizontal line from the crest on the spinous process of the third sacral vertebra. The P8 site lent itself to easier measurement with probes such as the Hennessy Grading probe (Phillips *et al*. 1987; Fig. 2.12). This probe was shown to over- and underestimate the fat depth of lean and fat carcasses respectively (Phillips *et al*. 1987; Hopkins 1989b) but it can be programmed to account for this divergence. The probe is used in abattoirs in several countries, including Australia. Probe measures at the P8 site have been found to be comparable to other measures for predicting yield in beef carcasses (Hopkins and Roberts 1993).

Apart from using carcass data for description purposes, it also provides for predicting meat yield – whether defined as saleable or lean – given the relationship between subcutaneous fat thickness and meat yield (Cole *et al*. 1962). Derivation of relationships between carcass measures such as subcutaneous fat thickness and carcass components, when combined with processing costs and component prices, allowed the calculation of break-even prices (Phillips *et al*. 1982) and thus construction by processors of price schedules or grids. Considerable work was undertaken in Australia to understand the factors that influenced such relationships (Johnson and Vidyadaran 1981; Bond 1984) to underpin the development of commercially robust systems which allowed carcasses to be traded on an objective basis (Anonymous 1981). With the shift to the P8 site, several studies were undertaken to establish the prediction error of using the P8 site compared to the 12th rib site (e.g. Ball and Johnson 1989) in which it was found that breed impacted on the relationship between fat depth at different measurement sites and meat yield. However, the inclusion of other carcass measures such as eye muscle area (EMA) has been shown to reduce breed differences in prediction models (Crouse *et al*. 1975;

Hopkins and Roberts 1993). Industry-wide prediction models for meat yield are difficult to make robust given the varying specifications that different companies use (Hopkins and Roberts 1993) and application of feedback systems based on yield to producers are usually company-specific.

The measurement of fat depth at the P8 site is now part of the AUS-MEAT language (Anonymous 2005a) used in Australia and abattoir employees can attain accreditation by demonstrating competence in the measurement of fat depth whether using the 'cut and measure' knife or the Hennessy Grading probe (Anonymous 2000). As a part of 'over the hooks' trading, processors must provide feedback to producers on P8 measures for each carcass, hot standard carcass weight, dentition, bruise score (1–9; dependent on the position on the carcass), with an option to provide a record of sex and butt shape (A–E; most convex to most concave respectively) (Anonymous 2005b). The bruise scoring system is described by Anonymous (2010b) along with a description of what is called a standard beef carcass. The AUS-MEAT language also includes classes for dentition (Anonymous 2005a).

Other methods for assessing and measuring beef carcasses have been developed, with the most widespread systems being video-based or using vision imaging. Early US research focused on a hand-held vision system for measuring the cut surface at the 12th rib as a means of improving the prediction of yield (Cross *et al.* 1983) and this approach was a forerunner of commercial systems.

There has been some development of alternate systems to measure carcasses at chain speed based on the use of video image systems for traits such as fat depth and carcass shape. Allen (2009) described five different systems. An extensive comparison of three systems was undertaken in Europe including the VIAScan® system which was developed in Australia (Ferguson 1993). In the European setting, the original research was designed to establish how closely the fat and conformation assessments of graders could be predicted by the video image based systems (Allen 2009). At this task, such systems were shown to be as good as, and in some cases better at, classifying carcasses than graders. The Danish BBC-2, German VBS2000 and Australian VIAScan® underwent more extensive evaluation (Allen 2009). Using vision systems to predict yield showed that the BCC-2 system was more accurate than graders (Borggaard *et al.* 1996) and the VIAScan® system was more accurate generally than using carcass weight and fat depth at the P8 site (Ferguson *et al.* 1995).

The VIAScan® system has a whole or quartered carcass measurement capability in the chiller. The former is installed on the slaughter floor and the latter is hand-held. Research in Canada using the VIAScan® whole carcass and chiller system found that together they provided a more accurate and precise prediction of meat yield and that the whole carcass system was superior to the more subjective system used in Canada (Jones *et al.* 1995). This was followed by work in the USA which showed that the whole carcass and chiller VIAScan® system could provide higher accuracies for yield prediction than using the US Department of Agriculture (USDA) grading system (Cannell *et al.* 1999). The research also highlighted the fact that the whole carcass system could provide yield estimates that could be used to group carcasses for boning, and thus improve boning room efficiency.

Figure 2.12: Measurement of subcutaneous fat depth at the P8 site using a Hennessy Grading probe. Source: D.L. Hopkins.

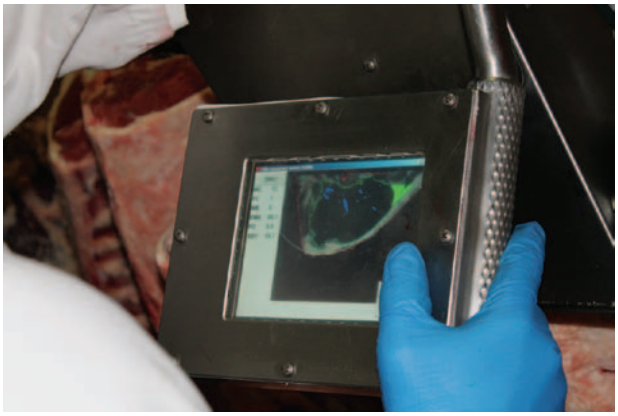


Figure 2.13: The video camera is placed over the quartered surface using the hand-held unit, enabling a range of traits to be measured. Source: Cedar Creek Co. Pty Ltd.

The Australian hand-held device (Fig. 2.13) allows measures of EMA, fat depth, marbling, fat colour and meat colour to be captured in the chiller and companies such as Woolworths are using it to provide feedback to suppliers (Anonymous 2010c). There has been limited adoption of the whole carcass system designed to give predictions of meat yield (Anonymous 2010c). In Ireland, the VBS2000 system was installed in 25 abattoirs to assess carcasses for fat cover and conformation (Allen 2009) and work was undertaken to extend the application to the prediction of yield (Pabiou and Berry 2009).

Technologies such as impedance and ultrasound have not been shown to be more useful or practical than the vision-based systems. Another approach to yield prediction is to track cuts through a boning room, but this requires the ability to track cuts and relate them to the original carcass. The Flowline system developed by Marel (Anonymous 2008) has potential in this area but linking data remains a challenge. If such a system could be developed, it would allow the direct determination of meat yield for each individual carcass without measurement of the carcass, but this would be after entering the boning room and thus would not streamline boning room efficiency based on expected meat yield.

Application of measures

Collection of carcass data can be used to streamline processing, specifically boning, provide feedback to livestock buyers and form the basis for payment to producers. To aid this process in Australia, a carcass ticketing system was developed. Carcass weight, fat depth and bruise score information is captured electronically and printed on the ticket with kill date, lot number and chiller destination information. This information is also summarised on feedback sheets that have the scope to give the weight, fat depth, dentition, butt score, sex and health status of each carcass within a lot, which can be sent back to producers. The carcass ticket provides processors, wholesalers and retailers with information that can be used to:

- provide an estimate of the yield of saleable meat;
- indicate the level of trimming required;
- determine the post mortem age of the carcass;
- determine the sex and dentition (if printed).

Operators such as wholesalers who purchase sight unseen can also use the ticket to verify that their purchases from a processor meet their specifications.

CHILLING, BONING AND FREEZING

The purpose of chilling is to reduce body temperature to prevent undesirable bacterial growth so as to protect human health, but chilling regulations vary between countries. Manipulation of chilling regimes and holding temperatures is undertaken to maximise shelf life in terms of colour display and bacterial growth. Aerobic *Pseudomonas* spp. are the dominant bacteria responsible for spoilage at chill temperatures (Newton and Gill 1981). *Pseudomonas* utilise glucose in preference to other substrates and then degrade amino acids.

Chilling

Chilling is the process of cooling meat while the meat remains above its freezing temperature. The lower the temperature, the slower the bacterial growth and the chemical reactions that take place post mortem. Chilling serves to transfer heat from carcasses and offal to other objects. The refrigeration process involves combinations of heat transfer conduction and convection; Lovatt (2004) provided a detailed description of the importance of these factors for chilling. To chill carcasses, the temperature must be lower than the surface temperature and forced convection (from fans) carries heat away from the surface more quickly. It is replaced by internal heat through conduction until the temperature of the carcass equilibrates with the surrounding temperature.

Carcass surfaces dry as they chill and humidity and air flow both influence drying. Drying is an important part of microbial control (Koutsoumanis and Sofos 2004), but it also results in weight loss from carcasses. Rapid chilling in the early part of the chill cycle gives good microbial control and low weight loss. This can produce tough meat through ‘cold shortening’, dry the surface (degrading the appearance) and, in fat cattle, produce hard fat that requires higher levels of physical effort to remove during boning. If chillers are pre-cooled before they are loaded, to aid rapid chilling, condensation will form on overhead structures. At the start of loading a chiller, the chiller air temperature (and chiller surfaces) should be at or above the temperature that can be maintained during loading. Typically, the air temperature during loading is 5–10°C. If the chiller is pre-cooled below 5°C and the air temperature rises during loading, condensation will occur.

Commonly, much water is sprayed onto the carcass during dressing to satisfy regulations. This does not remove bacteria, but instead spreads them over the carcass. Minimising the use of water limits bacterial spoilage and helps reduce condensation in chillers. However, to reduce weight loss due to chilling and potentially also reduce the rate of carcass temperature decline, there has been some investigation of spray-chilling in Australia (Brereton *et al.* 2011), a procedure that is widely used in the USA. In this procedure, chilled water is sprayed on the carcasses while hanging in the chiller. This has been shown to be effective at reducing weight loss by imparting a 1% or more improvement in weight (Allen *et al.* 1987).

Chilling requirements for beef carcasses in Australia given below are according to the Australian Standard (Anonymous 2007a), but these vary according to country. There are separate conditions for hot-boning of carcasses.

- All carcasses must be placed under refrigeration within 2 h of stunning.
- Surface temperatures of carcasses, sides, quarters or bone-in major separated cuts must be reduced to 7°C within 24 h of stunning.

At temperatures below 7°C, most enteric pathogens do not proliferate (Koutsoumanis and Sofos 2004). These conditions can be varied if a processor develops an alternative chilling program that is approved. Export processors must validate their chilling programs using the Refrigeration Index (RI) which is based on the predicted growth of *E. coli* (for model details see Ross *et al.* 2003). The RI applies to the site of microbiological concern (i.e. the slowest cooling point). Alternative chilling programs are often required if heavy grain-fed cattle are processed, as they are difficult to chill quickly. A calculator has been designed (Anonymous 2006b) to allow processors to calculate the RI for differing chilling cycles. These cycles will commonly include load, active chill and hold phases (for further details see Anonymous 2007b). Carcasses must be spaced in the chiller so that there is air movement over all surfaces. Touching surfaces cool slowly and do not dry; they provide ideal conditions for microbial growth. There has been extensive work in Europe on the application of very fast chilling (VFC), which is defined as achieving a muscle temperature of –1°C by 5 h post mortem (Joseph 1996). Any application in beef would be restricted to hot-boned meat given the difficulty of chilling the deep muscles of beef carcasses. Various chilling methods have been investigated, such as air, plate or immersion chilling. Obtaining a consistent improvement in tenderness is a problem with VFC (Dransfield and Roncales 1998), as there can be a decrease in sarcomere length that must be counteracted by increased proteolysis to produce a tenderness gain. For this reason, commercial application has not occurred.

For chilling hot-boned carcasses, processors must comply with the guidelines given below (Anonymous 2007a):

- The RI average is to be no more than 1.5, with only 20% of the refrigeration indices above 2, with no RI above 2.5.

For meat chilled in cartons, the heat transfer is different and the thermal resistance of the packaging and trapped air increase the time required to lower the meat's temperature. For this reason cartoned meat should be stored in chillers operating at lower temperatures.

Boning

Boning can be carried out before any significant cooling of the carcass occurs (i.e. hot-boning) or after chiller cooling in Australia when the temperature has reached <7°C on the surface. There is a growing trend for carcasses to be broken into primals and in some cases retail-ready cuts at the place of processing. This reduces transportation costs and means waste fat and bone can be used more effectively by rendering on site as opposed to being collected from retail outlets. The full range of primals and cuts produced in Australia are outlined in the Australian Handbook of Meat (Anonymous 2005a).

Hot-boning

There are many economic benefits for using hot-boning, including increased meat yield, energy savings, chiller space minimisation, reduced labour and time (McPhail 1995). However, there are disadvantages that include initial costs, changes in cut shape, marketing of product (Pisula and Tyburcy 1996), increased risk of shortening thus leading to toughening (Devine *et al.* 2004), and the increased risk of bacterial problems (Spooncer 1993). The increased risk of shortening in muscles can be minimised by the use of electrical stimulation. Electrical stimulation accelerates the onset of rigor mortis and reduces cold-induced shortening (Hwang *et al.* 2003). Additionally, bacterial growth in hot-boned meat can be controlled by a combination of drying and cooling of the carcass (Spooncer 1993). Hot-boning is applied in Australia to aged cattle that have been culled from herds, with several abattoirs solely processing cattle using this procedure. It is widely used in New Zealand.

Cold boning

Cold boning is currently the preferred method for beef apart from aged (cull) cattle because of the adverse effects on eating quality of hot-boning without other forms of intervention. Several different aids have been developed to help lessen the human energy required to bone beef carcasses, but many have not been adopted commercially. A robot to undertake scribing, so as to accurately establish cutting lines, is under development (Anonymous 2011b; Fig. 2.14). A robotic beef splitter is also under development, along with a hook assist system for helping boners to bone both hind and fore quarters, and a system to assist with ribcage removal.

Knuckle pulling and aitch boning are the most arduous boning room tasks in beef processing. For this reason aids have been developed, such as the Robotic Technologies Ltd beef boning unit which is now used commercially in Australia, New Zealand and Brazil. The device (Fig. 2.15) is a mechanical arm that provides a pulling force to aid the boner in rail boning. Reported benefits include meat yield gains and reduced boner fatigue and strain injuries. It is likely that developments in X-ray scanning technology to accurately determine cutting lines will occur in the future (Templer 2004), but it remains to be seen how extensively automatic boning systems are applied for beef. With a diversity of markets, there is a wide range of cuts that can be produced. Research has shown that use of overfat carcasses costs money through reduced boning room yields and increased preparation costs. A major product of beef processing is beef trimmings used for manufacturing minced meat. With a growing consumer demand for lean mince, on-line systems have been developed to ensure compliance with agreed fat levels and replace more manual systems based on the use of sampling and microwave testing. One such approach uses near infrared (NIR) scanning (Wold *et al.* 2011) to measure the fat content in trimmings on a conveyor before being boxed. It has removed the need to grind the trimmings before measurement.

Figure 2.14: Beef scribing robot. Source: Machinery Automation & Robotics.

Figure 2.15: Beef boning unit, involving a mechanical arm. Source: Robotic Technologies Ltd.

Freezing

Freezing meat requires the removal of heat so the water content of meat can be frozen (i.e. turned into ice) and this involves nucleation and growth of the ice crystals (Devine *et al.* 1996). Meat does not freeze until its surface temperature drops to the initial freezing temperature of the meat, and the latent heat must be removed. Once nuclei form, ice crystals start growing by accumulation of molecules at

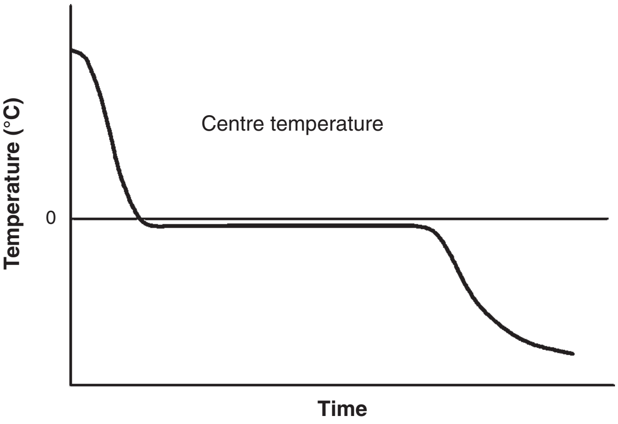


Figure 2.16: A typical temperature profile at the centre of meat during freezing. Source: S.J. Lovatt.

the solid/liquid interface; this process works from the outside inwards. A pattern of freezing is shown in Fig. 2.16, demonstrating that the time for complete freezing can be determined if the centre temperature is measured. At –7°C, 80% of the water is frozen (Devine *et al.* 1996).

The size of ice crystals depends on the rate of freezing. Fast freezing results in small ice crystals, but long periods of cold storage will allow ice crystals to grow larger. Large ice crystals can cause rupture of muscle cells, leading to increased drip loss on thawing and to physical degradation of muscle structure, but there appears to be an interaction with the storage temperature as to the extent of this effect (Ngapo *et al.* 1999).

Plate freezing will freeze carton meat much faster than air-based systems, as long as product thickness is 100 mm or less (Lovatt 2004). Plate freezers are based on product (in this case meat) being pressed between hollow metal plates that contain circulating refrigerant, but are not suitable for irregular-shaped products. For them, air-blast freezing is required.

PROCESSING METHODS AND TECHNOLOGY TO ENHANCE QUALITY

The processing of meat can impact on the visual and technological characteristics such as meat colour and keeping quality respectively, but also the organoleptic traits such as tenderness and flavour. Flavour, juiciness and tenderness influence the palatability of meat. Among these traits, tenderness is ranked as the most important for beef (Thompson 2002).

Post mortem effects on tenderness are largely related to the extent of contraction of unrestrained muscles after slaughter, the pH of the meat (influenced by stress), and the degree and method of cooking. The toughness of connective tissue is not affected by pre- and immediate post-slaughter handling techniques, but is influenced by factors such as animal age (Shorthose and Harris 1990). By comparison, the contribution of the contractile component to the final tenderness of a muscle is influenced primarily by pre- and post-slaughter handling techniques. The tenderness of different muscles varies significantly (Belew *et al.* 2003).

The processes affecting meat tenderness start at slaughter and the endogenous enzymes responsible for proteolysis, and thus tenderisation, are active throughout the rigor process. While proteolysis is taking place, significant tenderness changes are not evident until most of the muscle fibres are in rigor (Devine and Graafhuis 1995). The development of rigor and the shortening of fibres would be expected to counter early proteolysis so that the expected peak in shear force is eventually negated by the cumulative post-rigor proteolysis (Hopkins and Thompson 2002). Once the rise in toughness resulting from rigor contractures is complete, the process of tenderisation occurs. Under cooling conditions, those fibres at elevated temperatures will enter rigor early and will experience initially faster tenderisation (Hwang and Thompson 2001a). Several technologies have been developed to improve the tenderness of beef. These are outlined below.

Electrical stimulation

Electrical stimulation involves passing an electric current through the body or carcass of freshly slaughtered animals. The electric current causes the muscles to contract, increasing the rate of glycolysis and resulting in an immediate fall in pH (ΔpH that ranges from 0.6 pH units at 35°C to 0.018 units at 15°C). The energy of activation of ΔpH in stimulated beef *m. sternomandibularis* is calculated to be 97 kJ/mol (Chrystall and Devine 1980), or very similar to that for calcium-activated actomyosin ATPase (Bendall 1969). Following the ΔpH, there is a temperature-dependent acceleration of glycolysis (dpH/dt) and subsequent early rigor mortis development. In non-stimulated beef *m. sternomandibularis*, the energy of activation of the glycolytic process is 40–45 kJ/mol, whereas for stimulated muscle it approaches 70 kJ/mol (Chrystall and Devine 1980). The high energy of activation in both cases means that any cooling of the muscles will markedly increase the time for attainment of rigor mortis, with a larger effect in stimulated muscle. Thus tenderness measured at the completion of rigor mortis (the earliest possible time) will be substantially different for electrically stimulated muscles than for non-stimulated muscles, due to a difference in the rate of rigor development. It is important to remember that rigor development does not occur across all muscles simultaneously with a concomitant fall in pH. Jeacocke (1984) showed that for single fibres there was a contracture as the final ATP disappeared (i.e. rigor) and each fibre had its own time course depending on initial glycogen.

The combined effect is that the muscles enter rigor mortis before the muscle temperature falls to values producing cold shortening and toughening. A rule of thumb in the prevention of cold shortening is to maintain the muscle temperature above 10°C until pH falls below 6.0. The classic studies of Locker and Hagyard (1963) showed minimal shortening at close to 15°C and this correlated with minimal meat toughness, indicating that this should be an ideal temperature for rigor mortis to occur.

The incorporation of a practical electrical stimulation system into the slaughtering process to avoid toughness resulting from cold shortening was first used in New Zealand in the 1970s and then in Australia. It followed early research which demonstrated the benefits of stimulating beef carcasses (Davey *et al.* 1976). While electrical stimulation ensures that cold shortening is avoided, ageing also starts at a higher temperature and is consequently more rapid and thus, even under conditions where cold shortening does not occur, there are benefits from stimulation at least in terms of early tenderness levels (Strydom *et al.* 2005). There is also some evidence that there are other mechanisms involved in tenderisation, such as fibre disruption and modification of the enzyme systems, but most importantly, the stimulation alters the pH/temperature relationship of meat entering rigor. Hwang *et al.* (2003) reviewed mechanisms involved in the stimulation of muscle. Stimulation is now widely used in many other countries with a variety of parameters (Devine *et al.* 2004).

As outlined earlier, a new generation of systems has been developed in Australia for electronic bleeding, but these also have a stimulation effect. With parameters such as 5 Hz, constant current of 500 mA and a pulse width of 200 msecs they have replaced some manually applied low-voltage systems used in many Australian beef abattoirs. Under previous state regulations in NSW, for example, every abattoir had to have a stimulation system; these were almost exclusively low-voltage manually applied systems. The new systems have the advantage of applying the current on a moving carcass while still being safe.

In a new approach developed in Australia, each carcass is stimulated individually using segmented electrodes to ensure that each segment contacts only one carcass at a time. This allows computer-controlled electronics to give a precise, but adjustable electrical input to each carcass, thus matching the requirements of a particular carcass type while maintaining the delivery of a pre-determined level of current. It is a feedback system which detects the level of resistance. This approach also reduces costs related to occupational health and safety. This is because the power levels and pulse widths eliminate the need for isolation of the unit, which is a requirement of high-voltage systems, and the levels comply with occupational health and safety regulations according to Australian Standard 60479–2002 (Anonymous 2002a).

The timing of the application of stimulation after death has an effect on tenderness levels, with the suggestion that early (e.g. 3 min after death) high-voltage stimulation can lead to tougher meat than stimulation 40 min after death (Hwang and Thompson 2001b). This effect is attributed to shorter sarcomeres and autolysis of the calpains. Given the rapid post mortem decline in pH of heavy fat carcasses (Hopkins *et al.* 2007) it has been suggested that stimulating such carcasses is detrimental to eating quality (Hwang and Thompson 2001b). Care needs to be taken in this regard, as Hwang and Thompson (2001b) lacked the necessary controls to fully substantiate this conclusion. Others have suggested that stimulation can have a protective effect, enhancing tenderness under rapid pH decline conditions (Rosenvold *et al.* 2008). Further work is required to clarify the benefits or otherwise of stimulating carcasses that naturally exhibit rapid rates of glycolysis.

There is good evidence that heat toughening conditions of high temperature and low pH (HTLP), defined here as pH <6 and temperature >35°C, occur in many beef carcasses in Australia (Hopkins *et al.* 2007). The cause of HTLP could be a slow reduction in temperature, a rapid reduction in pH, or a combination of these two effects that are partly co-dependent; hence the link to stimulation as a potentially causative factor. The HTLP condition does not always lead to a reduction in eating quality of short aged product (Hopkins *et al.* 2013), but can do so when the product is aged for longer periods than meat that has not experienced the HTLP condition (Warner *et al.* 2013). Other effects can include increased purge and potentially lower redness of displayed meat (Hopkins *et al.* 2013). A comprehensive review has recently outlined processing approaches to reducing the occurrence and impact of HTLP (Jacob and Hopkins 2013).

Pelvic suspension: tender stretching

Traditionally, carcasses have been suspended by the Achilles tendon, which causes some economically significant muscles to shorten (Hostetler *et al.* 1970), increasing the toughness of the meat. Pelvic suspension (Tenderstretch) allows the hind limb to fall into a natural 90° angle (Fig. 2.17) and changes the position of the muscles of the hindquarter, restricting some muscles from contracting during rigor (Bouton *et al.* 1973b) and improving tenderness in those muscles (Table 2.2). The effect is only seen in the hindquarter muscles and in some muscles there is no improvement (i.e. *M. biceps femoris* and *M. semitendinosus*). The latter muscle is stretched in Achilles-hung sides and in the case of the *M. psoas major* it actually shortens in tender stretched carcasses. The reduction in shear force in muscles due to pelvic suspension reflects increased sarcomere length, particularly in the *M. semimembranosus* (Bouton and Harris 1972) and *M. longissimus lumborum* (Bouton and Harris 1972; Sørheim *et al.* 2001) thereby improving the tenderness of the topside and striploin and cube roll respectively. Pelvic suspension results in tenderness at 2–3 days after death equal to that of 3 weeks ageing in Achilles-hung carcasses (Bouton *et al.* 1973b). Commercial adoption of this technique has seen resurgence as processors have developed ways to handle and store tender stretched carcasses, such as adopting methods to re-hang carcasses from the Achilles tendon after attainment of rigor, streamlining carcass movement and boning. This has been stimulated in Australia by the development of MSA and evidence that sensory tenderness could improved by up to 20% in muscles like the *M. semimembranosus* using Tenderstretch (Park *et al.* 2008).

Fig. 2.17: With pelvic suspension (Tenderstretch) the carcass is suspended by the aitchbone so that back leg drops, the backbone straightens and maximum tension is placed on hindquarter muscles. Source: E. Toohey.

Pelvic suspension (Tenderstretch) alone has not been patented. Cargill Inc. in the USA has patented pelvic suspension (Gardner *et al.* 2007) as part of a wider meat tenderisation system incorporating separating vertebrae (a variant of the Tendercut technique below), pelvic suspension, electrical stimulation and immediate subsequent Achilles suspension. In this methodology, pelvic suspension is used for less than 10 min, preferably less than 2 min, restricting muscle contraction only as the muscles approach rigor. No claims are made as to the efficacy of this process. Pelvic suspension following electrical stimulation has been patented by Devrone Ltd in Ireland (McDonnell 2003). In this system, the carcass undergoes electrical stimulation immediately on death (before

Table 2.2: Warner-Bratzler shear values (N) for muscles measured at 2–3 days post mortem obtained from sides of beef hung by the Achilles tendon or aitchbone (Tenderstretch)

	Method of suspension	
Muscle	**Achilles tendon**	**Aitch bone**
Semimembranosus	82.3	50.0
Gluteus medius	78.4	39.2
Longissimus	107.8	55.9
Vastus lateralis	86.3	52.9
Biceps femoris	63.7	65.7
Semitendinosus	59.8	58.8
Infraspinatus	62.7	58.8
Psoas major	35.3	49.0

Source: Adapted from Bouton *et al.* (1973b).

skinning and evisceration) and Tenderstretching is applied to half-carcasses just before entering the chiller. No claims have been made about the efficacy of this process.

Criticisms of pelvic hanging include the altered shape of the hind leg and some cuts of meat, and an (alleged) greater space requirement for carcasses. However, the altered shape of the hind leg makes it easier to carve and the space requirement is reduced if the carcasses are arranged to interweave in the chiller. Another advantage of the method is that chiller height can be reduced, which could translate into lower energy costs with smaller volumes to chill. This method is a logical approach for processors wishing to market a high-value product and there is some adoption of the method among Australian processors.

Tendercut (skeletal separation)

Tendercut is a process developed in the USA (Claus *et al.* 1997) by which additional stretch is applied to pre-rigor target muscles by separating the skeleton and connective tissue, leaving only the muscle to hold the weight of the carcass below the split. This process involves sawing the vertebral column at the 12th/13th rib junction and/or the ischium at the rump/butt junction. In addition to breaking the vertebrae at the 12th/13th rib junction, all tissues surrounding the loin are cut, such that it is the only dorsal component holding the forequarter to the hindquarter. The adipose tissue dorsal to the *longissimus* muscle is cut to expose the epimysium; this cut is then continued around the medial side of the loin muscle and the *M. multifidus dorsi* is completely severed. Intercostal connective tissue and muscle are then cut between the 12th/13th costal bones. This latter cut is extended ~12 cm from the lateral edge of the loin muscle. The second cut severs the ischium at the site used to separate the butt/rump joints, the junction between the 4th/5th sacral vertebrae and connective tissues. The fillet muscle must be freed from its attachment and deflected forward during sawing. The carcasses are hung in the traditional manner by their Achilles tendons (Fig. 2.18). The aim is to increase tenderness in the *M. longissimus lumborum* and in the hindquarter muscles by increasing sarcomere length through stretching and by preventing sarcomere shortening during rigor.

Figure 2.18: The severed vertebral column, part of the Tendercut method. Source: J.R. Claus.

Research on the benefits of Tendercut has produced variable results. The greatest improvement in tenderness was found in carcasses that were not inherently tender (Claus *et al.* 1997). While research has shown an increase in sarcomere length resulting from the Tendercut process (Claus *et al.* 1997; Wang *et al.* 1996) this was not always matched with a commensurate improvement in sensory response or in shear force results (Wang *et al.* 1996; Shanks *et al.* 2002). Tendercut was found to have a favourable impact on shear force and sensory results only if the carcasses were rapidly chilled (Sørheim *et al.* 2001), and there was no reduction in shear force or improvement in sensory tenderness in medium chilled carcasses. This may account for the variation in results from different studies.

Research into other economically important meat traits has also shown variable results. Tendercut has no effect on cooking loss (Claus *et al.* 1997; Ludwig *et al.* 1997) or thaw loss (Ludwig *et al.* 1997). Ribeye/cube roll cross-sectional area was unaffected by Tendercut in some studies (Wang *et al.* 1996; Ludwig et *al.* 1997), while being significantly reduced in others (Claus *et al.* 1997). A reduction in the ribeye area may change the USDA yield grade in beef produced in the USA. Colour was unaffected by Tendercut in some studies (Wang *et al.* 1996; Ludwig *et al.* 1997), while a significant reduction in redness was found in others (Claus *et al.* 1997). This reduction was attributed to the exposed muscles being chilled more rapidly. Although Tendercut was not patented by its developers, a version of the Tendercut process incorporated into a processing chain with electrical stimulation has been patented by Cargill Inc. in Minnesota (Bell *et al.* 2005). Further detail on the application of this procedure is given by Taylor and Hopkins (2011). The major benefit of Tendercut is that the process can be incorporated into existing meat processing chains without altering equipment.

As meat cuts can be tenderised by pre-rigor or post-rigor treatment, several methods have been developed accordingly. For pre-rigor cuts there are two novel methods for tenderising cuts: Pi-Vac Elasto-Pack system and SmartShape™/SmartStretch™ (Taylor and Hopkins 2011). Several methods have been developed for post-rigor cuts, such as blade tenderisation, ultrasound, hydrodynamic pressure and hydrostatic pressure (for further detail see Hopkins 2004). These methods can be used in combination with ageing.

Pi-Vac Elasto-Pack System®

The Pi-Vac Elasto-Pack System® is a method of tightly wrapping hot-boned muscles in an elastic wrapping material pre-rigor to prevent shortening and toughening of the meat. The system uses a highly flexible packaging sleeve, which is expanded using a partial vacuum to allow the meat to be inserted. Once the vacuum is turned off, the flexible packaging retracts to its normal dimensions. This exerts longitudinal forces on the meat, preventing the contraction of the muscle. Almost all the oxygen is also forced out of the packaging (Troy and Kerry 2010; Sørheim and Hildrum 2002). The subsequent bound meat product has been labelled TenderBound (Troy 2006) and is displayed in three different sizes (Fig. 2.19). Adopting the concept of super tenderstretching by using weights (Hopkins *et al.* 2000) and applying it to hot-boned beef muscle, O'Sullivan *et al.* (2003) showed that equivalent tenderness could be achieved to that realised with the Pi-Vac Elasto Pack System®. The Pi-Vac Elasto Pack System® produced meat with the lowest variation, indicating that this method does something to meat structure that is different from other forms of stretching. O'Sullivan *et al.* (2003) and Troy (2006) reported a reduced drip loss as a result of Pi-Vac Elasto Pack System® treatment of hot-boned beef *M. longissimus.*

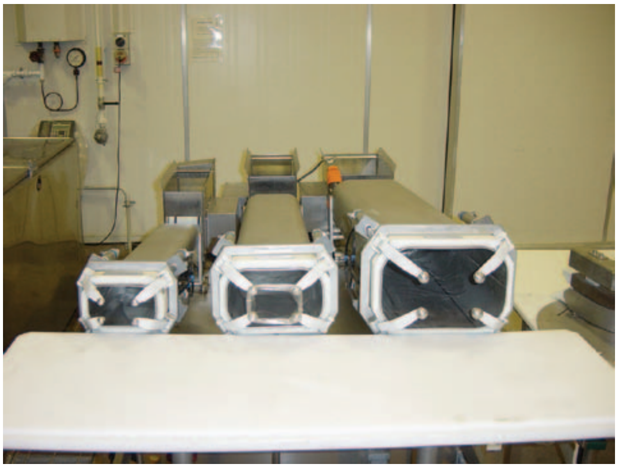


Fig. 2.19: The Pi-Vac Elasto-Pack System showing three different sizes. The middle size shows the plastic film that is used inside the machine. Source: C. Devine.

Smartstretch™

This technology was designed to apply air pressure to excised individual pre-rigor muscles to stretch the muscle into an even form and package it so as to retain that form. The technology was patented by Meat and Wool New Zealand Ltd and Meat and Livestock Australia Ltd (Pitt and Daly 2008) as the 'Boa' and was subsequently registered as SmartStretch™. As with all stretching systems, the aim was to either stretch sarcomeres or to prevent the contraction of sarcomeres during rigor, with some resultant tenderness benefits. The machine's operation is based on an externally ribbed flexible sleeve surrounded by inflatable bladders that are housed within an airtight chamber from which air can be pumped in or out. Air is pumped out of the chamber to create negative pressure which causes the sleeve to expand, allowing the meat to be inserted. Air is then pumped into the inflatable bladders, causing the meat to be compressed by force perpendicular to the direction of the muscle fibres. This also applies peristaltic action, moving the meat towards the same end of the sleeve into which it was inserted. Positive pressure is then applied to the exterior of the sleeve by pumping air into the chamber, forcing the meat upwards and into packaging (Fig. 2.20).

As with the Pi-Vac system, the application of SmartStretch™ is for hot-boned muscles and most work has been conducted in Australia with beef from aged cows. Several

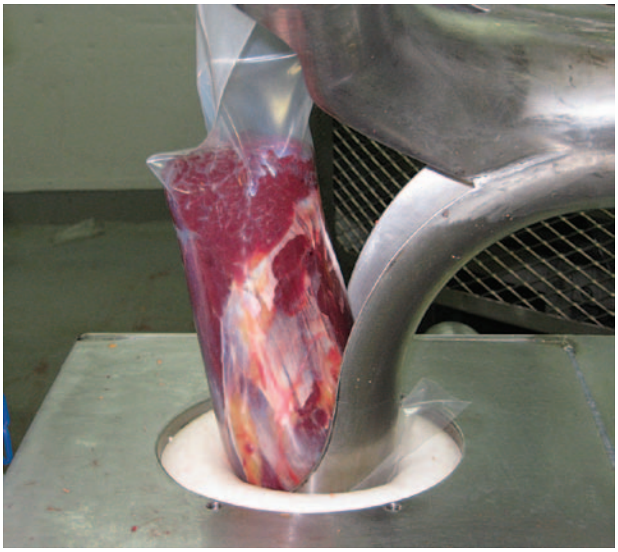


Figure 2.20: Stretched beef being ejected from the flexible sleeve into the packaging. Source: D.L. Hopkins.

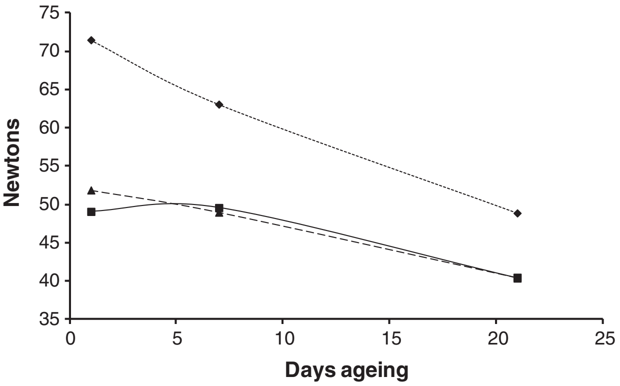


Figure 2.21: Effect of hanging/stretching method and ageing on tenderness. Source: Adapted from Geesink and Thompson (2008). ◆......◆ = Achilles-hung carcasses; ■—■ = Tenderstretch hung carcasses; ▲- - - - ▲ = SmartStretch™ treated meat.

of the studies conducted on beef *M. semimembranosus*, *M. longissimus lumborum* and rostbiff (mainly *M. gluteus medius*) were inconclusive as to the SmartStretch™ system's impact on beef tenderness (Taylor *et al.* 2010; Toohey *et al.* 2010). Increasing stretch in the *M. semimembranosus* from 34% to 52% had no impact on shear force (Toohey *et al.* 2010), but it was suggested that this might reflect the fact that once a basal level of stretch was achieved, further stretching would not have an effect (Simmons *et al.* 1999). A 21% increase in length of the *M. semimembranosus* and rostbiff also had no significant impact on shear force or sensory results (Taylor *et al.* 2010), although the shear force values were so high that tasters could not discriminate between the tough and the extremely tough product. A reduction in the variability in shear force was found.

If younger cattle (maximum dentition score of 2) were used, then the results showed a significant improvement in hot-boned meat tenderness from the use of SmartStretch™. Initial work in beef comparing SmartStretch™ to Tenderstretch, 'Superstretch' (Tenderstretch plus a pulley system to pull the hind limb towards the forequarter) and Achilles suspension showed similar tenderness improvements in the *M. longissimus lumborum* from all three stretching treatments in prime cattle (Geesink and Thompson 2008; Fig. 2.21). Subsequent work with young cattle showed that tenderness of the rostbiff *(M. gluteus medius*), as reflected in reduced shear force measurement, was significantly improved in 0 day aged stretched samples over the un-stretched hot-boned control (Taylor *et al.* 2012). After 8 days ageing, there was no longer a difference in the tenderness between stretch treatments. Sarcomere length was significantly increased by stretching in both studies. Presentation traits, such as purge loss and fresh colour, have been generally unaffected by the SmartStretch™ treatment.

Ageing

Ageing is the prolonged storage of meat at temperatures above freezing. There is strong evidence that specific myofibrillar muscle proteins are degraded during the post mortem ageing period (Bandman and Zdanis 1988), leading to a substantial reduction in the tensile strength of muscle fibres and thus in toughness. Several reviews summarise the biochemical changes which occur in meat during the post mortem period (Koohmaraie 1996; Ouali *et al.* 2006; Hopkins and Geesink 2009). It is contended that the calpains are the main group of proteolytic enzymes responsible for the changes (Hopkins and Geesink 2009).

The rate of ageing varies with temperature and time. At low temperatures such as 0°C, a longer time is required for an equivalent effect and ageing will be less effective. If muscles are badly cold shortened, they will be so tough that even after ageing for 3–7 days consumers would still consider the meat unacceptable. The effect of time is illustrated in Fig. 2.22 for carcasses and primals chilled at 1°C then held at the same temperature. After 21 days, the shear force values for meat from the Achilles-hung carcasses was more than 40% lower than at 1 day. By contrast, meat from the Tenderstretched carcasses or from SmartStretch™ treatment showed an immediate reduction in shear force at 1 day of ageing and a similar rate of ageing. Ageing enables processors and retailers to meet consumer-acceptable tenderness levels when the target shear force is 40–45 N (Perry *et al.* 2001). This is consistent with the mean ageing time being ~20 days for loin steaks at retail in the USA (George *et al.* 1999).

STEPS TO ENHANCE TENDERNESS

- Avoid rapid chilling of non-stimulated carcasses.
- Condition carcasses before chilling – under Australian conditions for fresh/chilled product this could only be adopted by holding carcasses at 7°C for 1–2 h before full chilling.
- Electrically stimulate carcasses – this offers the simplest approach to ensuring tenderness while not comprising public health safety and keeping quality.
- Tenderstretch carcasses.
- Monitor product for tenderness (either by use of the shear test or by an in-house panel) and chillers for effective operating temperatures.
- Age meat for at least 14 days before consumption (can vary with cut).

Vacuum-packing

The shelf-life of beef cuts can be extended by up to 10–12 weeks through vacuum-packing (South 1995). In a vacuum pack, there is not enough oxygen to support the growth of normal spoilage bacteria. Other bacteria can grow on meat in vacuum packs but they do not spoil the meat as quickly as the bacteria that grow in air. However, the shelf-life of vacuum-packed chilled meat is very sensitive to how the meat is prepared and packed and to the storage temperature, with lower temperatures being preferred (e.g. 0°C).

Cutting boards are a major factor in the spread of bacteria during boning, particularly when carcass contamination is at low to moderate levels. To limit the spread of bacteria, it is recommended that badly scored cutting boards should not be used because they are difficult to clean and if meat is heavily contaminated (from ageing or frequent handling), there will be a benefit from changing boards regularly (Widders *et al.* 1995) (recommended at 1 hourly intervals). Boards should be scrubbed and cleaned with hot water and a solution of 0.1% hypochlorite.

Shelf-life is also sensitive to the pH of the meat. If the pH of the meat is above 5.8, bacteria that cause greening of the meat can grow in the vacuum pack and cause early spoilage (Egan and Shay 1988). Meat pH can be measured with a pH meter and only meat with a pH <5.8 should be vacuum-packed if a shelf-life of more than 4 weeks is required.

After several weeks of storage, vacuum-packed beef may not match the appearance of fresh beef when it is removed from the vacuum pack. In particular, the fat surface may be slightly discoloured or stained from weep in the pack. It is important that carcasses with white fat be used to source cuts for vacuum packing when the markets are discerning about fat colour so that, after ageing, the colour will be acceptable. The other consideration is the stability of the meat colour; modification of the atmosphere by the use of gases such as carbon dioxide is advantageous (McMillin 2008). This process is called modified atmosphere packaging (MAP). Whole primals can be stored under MAP and major retailers are increasingly using this approach to aid tenderisation and supply. The evidence that MAP conditions always improve tenderness or eating quality is not conclusive (Zakrys *et al.* 2008, 2009), but there is an upper oxygen limit before the development of oxidative flavours that cause unacceptability (Zakrys *et al.* 2008). These factors mean the application of MAP must be carefully applied.

Shelf-life can also be extended by treating carcasses or cuts with organic acids, such as acetic acid which exhibits a residual activity that prevents the growth of pathogens (Carpenter *et al.* 2011), although the reduction in bacterial contamination is variable between different organic acids. In the USA, organic acids can be applied as part of the carcass wash pre-chill (USDA/FSIS 2011), but their use is not permitted in the EU. If primals are treated the meat should be drained for a short time then vacuum-packed as normal.

A range of modified atmospheres can be used for packaged beef cuts. The packing systems use an oxygen-impermeable film similar to the film used for vacuum-packing. The packs are filled with a gas mixture at the time of packing. The required volume of gas is up to 3 times the volume of the meat. For a long shelf-life (20 weeks) pure carbon dioxide should be used, the residual oxygen in the pack must be <0.2% and the storage temperature 0°C.

A gas mixture of 80% oxygen and 20% carbon dioxide can be used to give meat a bright and attractive colour in retail display. Beef packed in this gas mixture has a shelf-life of 7–10 days at 0–2°C. Another version of MAP is retail-ready cuts in a master pack. In this style of packing, retail cuts are packed in oxygen-permeable film such as polyethylene, and the packs are placed in a master pack of

Table 2.3: Major packaging types and characteristics for fresh retail meat

Package	Air-permeable overwrap	Air-permeable overwrap in master pack	Vacuum skin packaging (VSP)	Low O_2 with CO_2 and N_2	Peelable VSP or low O_2 with CO_2: N_2	Low O_2 with CO	High O_2
System description	Air-permeable film overwrap of product on tray; product displayed in package	Barrier bag with single or multiple trays of product in air-permeable packaging; trays removed for retail display	Flexible film shrunk around product on a rigid base web; product displayed in package	Thermoformed or preformed trays with lidding film; may be a master pack for product in air-permeable packages	VSP or barrier tray with 2-layer lidding film; outer barrier film peeled from inner permeable film before product display	VSP; may be thermoformed or preformed tray with lidding film; product displayed in package	Thermoformed or preformed tray with lidding film; product displayed in package
Gases in headspace	Atmosphere air	Usually CO_2 and/or N_2 in master pack	No gas headspace	CO_2 and/or N_2	No headspace with VSP; CO_2 and/or N_2	CO_2 and/or N_2; no headspace with VSP	O_2 and CO_2; often 80% O_2:20% CO_2
O_2 scavengers	None	Recommended	Sometimes	Recommended	Recommended	Recommended	None
Meat colour in storage	Red	Purple	Purple	Purple	Purple	Red	Red
Meat colour for display	Red	Red	Purple	Purple; red after removal from master pack	Red	Red	Red
Whole muscle shelf-life, days at 4°C	5–7	10–14	60–90	30–60	30–45	35	12–16
Minced or ground shelf-life, days at 4°C	2–3	7–10	45–60	20–40	20–30	28	10–12
Display life, days	2–7	2–7	30–60	15–40	2–7	28–35	7–16
Drip loss, %	8–10	3–5	2–5	1–5	0–7	1–7	0–5
Advantages	Consumers familiar with packaging; high product visibility; lowest cost; multiple sizes on same equipment	Storage life extended before display	Long storage life before display; high product visibility	Long storage life before display	Long storage life before display; high product visibility with VSP	Long red colour stability and no lipid oxidation; high product visibility with VSP	Moderate red colour stability
Disadvantages	Short display life; leaky package if bottom sealed rather than tube sealed at ends	Double packaging costs; short display life; re-blooming after air exposure may be inconsistent	Display with purple colour	Purple display colour in MAP; scavengers increase costs; bloom may be inconsistent on exposure to air after removal from MAP; increased cost with master pack	Film peeling at retail store; may be mottling or inconsistent bloomed colour after air exposure; short display life; increased package and scavenger costs	Negative image by consumers; concern red products may be spoiled in other factors; scavengers increase costs; cooked meat colour may be pink	Lipid oxidation; may be bone darkening or decreased tenderness; headspace required; may be premature browning of cooked meat

Source: McMillin (2008).

oxygen-impermeable film. The master pack is flushed with carbon dioxide. The carbon dioxide helps preserve the meat during distribution and storage, and when the master pack is opened, the meat in the individual retail packs will bloom to bright red colour, ready for display. McMillin (2008) provides a comprehensive review of this area and a summary of the major packing types is given in Table 2.3.

Tips for extending keeping quality

- Minimise water use on the carcass during slaughter.
- Reject high pH meat.
- Minimise handling of the meat.
- Store cuts at 0°C.

GRADING BEEF FOR EATING QUALITY

Tenderness is a major factor in determining whether consumers will repeat-purchase meat like beef and the evidence indicates that western consumers are prepared to pay a premium for more tender beef (Miller *et al.* 2001). There has been limited worldwide adoption of systems to give beef consumers a guaranteed eating quality. In New Zealand, a Beef Quality Mark program was launched (Frazer 1997) in response to surveys which showed an unacceptable proportion of beef exceeded a pre-determined shear force threshold. Subsequent testing of New Zealand beef showed that between 1997 and 1999 the shear force of beef declined by 22%; this was attributed to the auditing intrinsic to the quality mark program (Bickerstaffe *et al.* 2001). Fundamental to compliance was the requirement for meat to have a pH <5.8 and for 95% of the samples to have a shear force less than 80 N (based on conversion of Tenderometer values using the model of Hopkins *et al.* 2011). Audits of beef tenderness in the USA showed little improvement between 1991 and 1996 (George *et al.* 1999) in a country which has relied upon a carcass trait only quality assessment system (Smith *et al.* 2008). In the USDA beef grading system, there are eight quality grades and carcasses are largely separated by maturity (assessed by ossification and size of the bones, and the colour and texture of the lean tissue) and marbling (Smith *et al.* 2008).

The ability of the USDA quality grades to predict tenderness varies according to the cut (Smith *et al.* 2008). The relationship between shear force and USDA quality grades also varies according to the cut, and for several cuts is poor (Powell *et al.* 2011). In the USDA system, the *M. longissimus lumborum* is the muscle used for assessment and, given that it is an imperfect predictor of the tenderness of other muscles in the carcass (Rhee *et al.* 2004), this limits prediction ability across the carcass.

A contrasting approach was adopted in Australia (MSA) based on development of a prediction model for the eating quality of beef (Thompson 2002) where anatomical cut descriptions were replaced with determination of the eating quality of muscles. An eating quality score was formed by weighting four sensory variables – tenderness, juiciness, liking of flavour and overall liking (Watson *et al.* 2008) – and then ratings given (ungraded, 3, 4 or 5 star), reflecting an increase in the eating quality score. The components of the current model were specified by Watson *et al.* (2008) as 1) the percentage of *Bos indicus* with an adjustment for hump height according to carcass weight, 2) sex, 3) carcass weight, 4) whether milk-fed veal, 5) carcass hanging method, 6) marbling (based on the USDA system; Fig. 2.22), 7) ossification (based on the USDA system), 8) subcutaneous fat depth at the quartering site, 9) ultimate pH (must be ≤5.7), 10) days ageing, 11) use of hormonal growth promotants (HGP) and 12) the cooking method for each cut or muscle. Meat colour is used as a threshold and if the score is above 3 (based on colour chips from AUS-MEAT; Anonymous 2005a) the carcass is not graded. Later work created categorisation based on selling method of the cattle, either saleyard or direct to the abattoir. Considerable work has been undertaken to demonstrate the impact of all these variables on the eating quality score and star rating.

The Australian-developed MSA system of grading beef has highlighted the real value differences between carcasses that were of similar type and is designed to improve the 'eating quality guarantee' which could be given to any piece of meat. For example, as discussed by Polkinghorne (2006), rump steak comprises different muscles that have various levels of eating quality that will also interact with cooking method, so the true value of the cut will shift depending on which muscles and cooking method are used. This approach challenged the concept that single muscle or carcass measures can be used to predict eating quality and thus true value. The model can provide an eating quality score for 46 muscles cooked by six different methods (Polkinghorne 2006) and more recently has been able to provide predicted eating quality scores for 135 'cut by cooking method' combinations (Polkinghorne *et al.* 2008b). An example of the output from the model is given (Fig. 2.23) for cuts/muscles cooked different ways, taken from a steer carcass not treated with HGP, weighing

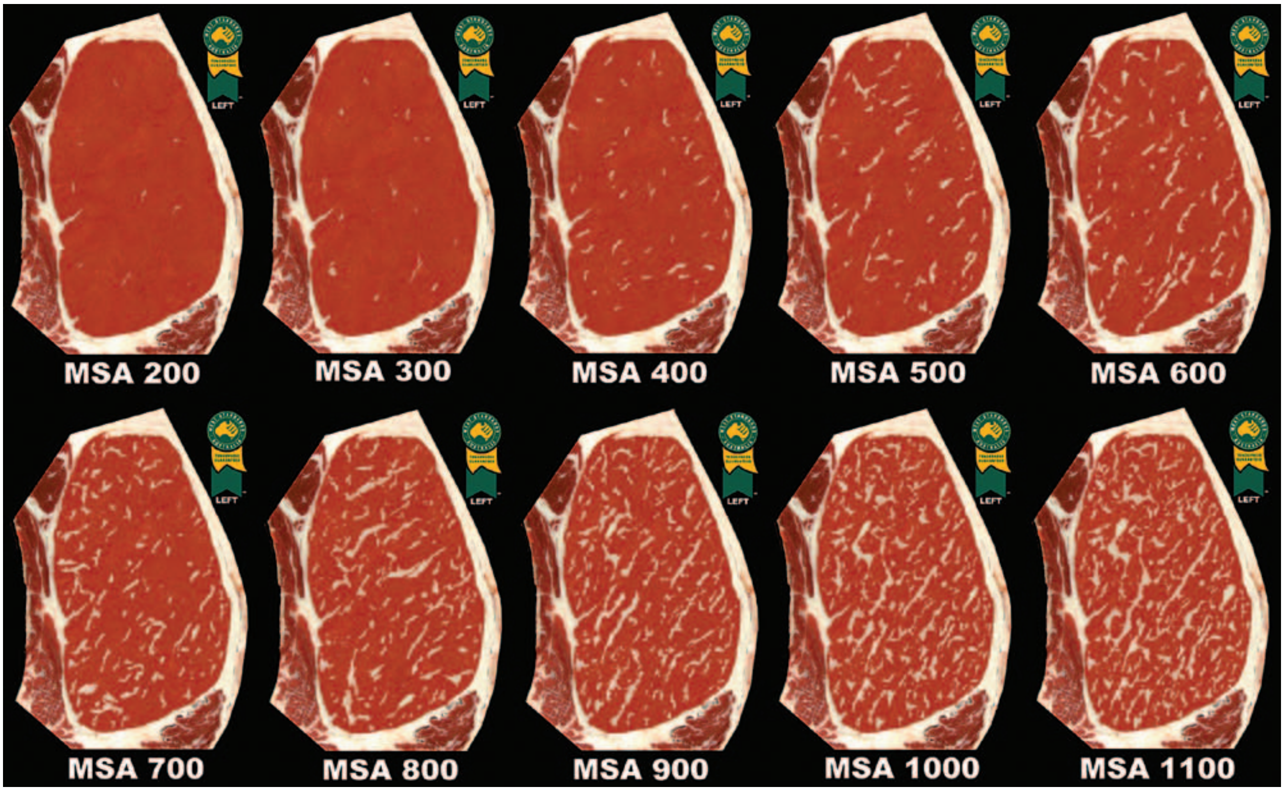


Figure 2.22: Pictorial representation of the marbling scores used in the MSA grading system. Source: MLA.

260 kg, with 25% *Bos indicus* content and a rib fat depth of 7 mm (Anonymous 2010d). The carcass was hung by the Achilles tendon, had an ossification score of 150, a marbling score of 270 and an ultimate pH of 5.55, and the cuts were aged for 5 days. This shows the reduction in eating quality when hind leg cuts are grilled, with roasting or cooking of the meat in thin slices producing a better result. The low content of connective tissue in the tenderloin is reflected by the higher eating quality score irrespective of the cooking method.

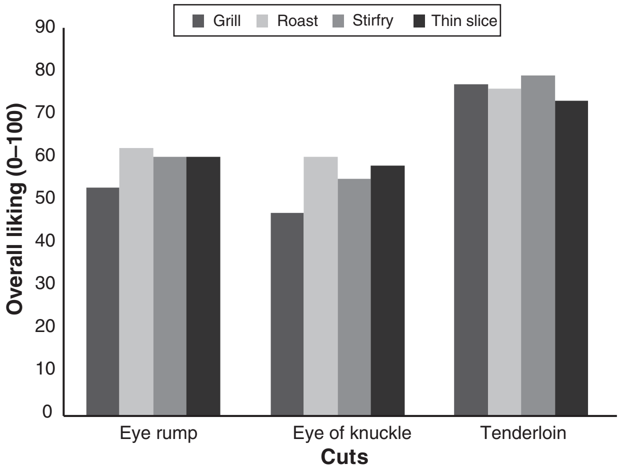


Figure 2.23: Effect of cut and cooking method on the eating quality (overall liking) of beef meat. Source: Adapted from Anonymous (2010d).

The MSA program has demonstrated that products can be marketed at the retail level according to predicted eating quality within cooking guidelines, without any mention of cuts (Polkinghorne 2006). This led to the development of new value-added products, more appropriate use of particular cuts such as topsides thin sliced and seam-boning (e.g. MSA 2010). Returns per carcass can be increased by adopting this approach (Polkinghorne *et al.* 2008a). Extensive work in North America has been conducted to characterise the meat qualities of muscles in lower-value cuts such as the chuck (Von Seggern *et al.* 2005) so that alternative uses of the cut could be made, applying the seam-boning approach. This work has led to a comprehensive profile of the beef carcass for a range of meat quality traits (Jones *et al.* 2005), but the traits did not include eating quality. In this sense the MSA approach stands alone in the world as the premier system for grading beef.

To produce high-quality beef meat, attention must be paid to the pre-slaughter nutrition and handling of cattle. This needs to be linked to processing which aims to maximise conditions for optimal eating quality and a system which rewards producers for the production of such meat. Having said this, it must be recognised that value chains exist for all sorts of beef meat products across the manufacturing to table meat spectrum.

REFERENCES

Allen P (2009) Automated grading of beef carcases. In *Improving the Sensory and Nutritional Quality of Fresh Meat*. (Eds JP Kerry and D Ledward) pp. 481–492. CRC Press, Boca Raton.

Allen DM, Hunt MC, Luchiari Filho A, Danler RJ, Goll SJ (1987) Effects of spray chilling and carcass spacing on beef carcass cooler shrink and grade factors. *Journal of Animal Science* **64**, 165–170.

Anonymous (1981) *Trading by Specification*. Department of Agriculture, Tasmania.

Anonymous (1988) *Meat Evaluation Handbook*. National Livestock and Meat Board, Chicago.

Anonymous (2000) *Advanced Carcase Fat Measurement*. Authority for Uniform Specification Meat and Livestock, Brisbane.

Anonymous (2002) *Australian Standard AS/NZS 60479. Effects of Current on Human Beings and Livestock*. Standards Australia, Sydney.

Anonymous (2002) Australian model code of practice for the welfare of animals. SCARM Report 79. CSIRO Publishing, Melbourne.

Anonymous (2005a) *Handbook of Australian Meat*. 7th edn. Authority for Uniform Specification Meat and Livestock, Brisbane.

Anonymous (2005b) *Guideline to Over-the-hooks Trading of Livestock*. Authority for Uniform Specification Meat and Livestock, Brisbane. <http://www.ausmeat.com.au/media/1713/overthehooksguide.pdf>.

Anonymous (2006a) Electrical inputs during beef processing. Meat Technology Update, 1/06. Food Science Australia.

Anonymous (2006b) *Refrigeration Index Calculator Version 3*. Meat & Livestock Australia, Sydney.

Anonymous (2007a) Australian standard for the hygienic production and transportation of meat and meat products for human consumption. FRSC Technical Report No. 3. CSIRO Publishing, Melbourne.

Anonymous (2007b) Beef carcase chilling: opportunities for customising programs. Meat Technology Update, 2/07. Food Science Australia.

Anonymous (2008) Flowline: big time value adding. *Australian Meat News*, February 2008, pp. 34–35.

Anonymous (2010a) MSA requirements for handling cattle. Meat & Livestock Australia, Sydney, Australia. http://www.mla.com.au/Marketing-red-meat/Guaranteeing-eating-quality/On-farm - accessed 14/10/2011.

Anonymous (2010b) *Beef and Veal Language*. Authority for Uniform Specification Meat and Livestock, Brisbane. <http://www.ausmeat.com.au/media/1756/BV-Lang%2010%20LR.pdf>.

Anonymous (2010c) VIAscan's new beginning. *Australian Farm Journal* **20**, 37–40.

Anonymous (2010d) *Meat Standards Australia Beef Information Kit*. Meat & Livestock Australia, Sydney. <http://www.mla.com.au/files/0e6b8058-df65-4d30-a60f-9dbc009760bb/msa-beef-info-kit.pdf>.

Anonymous (2011a) Effect of slaughter method on animal welfare and meat quality. Meat Technology Update, 1/11. Food Science Australia.

Anonymous (2011b) *Beef Scriber*™. Machinery Automation & Robotics. <http://www.machineryautomation.com.au/robotic/beefscribing.html>.

Anonymous (2012) *Australian Animal Welfare Standards and Guidelines: Land Transport of Livestock*. Animal Health Australia, Canberra. <http://www.animalwelfarestandards.net.au/>.

Apple JK, Kegley EB, Galloway DL, Wistuba TJ, Rakes LK, Yancey JWS (2006) Treadmill exercise is not an effective methodology for producing the dark-cutting condition in young cattle. *Journal of Animal Science* **84**, 3079–3088. doi:10.2527/jas.2006-137.

Arthur TM, Brichta-Harhay DM, Bosilevac JM, Kalchayanand N, Shackelford SD, Wheeler TL, Koohmaraie M (2010) Super shedding of Escherichia coli O157:H7 by cattle and the impact on beef carcass contamination. *Meat Science* **86**, 32–37. doi:10.1016/j.meatsci.2010.04.019.

Ball B, Johnson ER (1989) The influence of breed and sex on saleable beef yield. *Australian Journal of Experimental Agriculture* **29**, 483–487. doi:10.1071/EA9890483.

Bandman E, Zdanis D (1988) An immunological method to assess protein degradation in *post-mortem* muscle *Meat Science* **22**, 1–19. doi:10.1016/0309-1740(88)90023-X.

Barton Gade P (2004) Pre-slaughter handling. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 1012–1020. Elsevier, Oxford.

Belew JB, Brooks JC, McKenna DR, Savell JW (2003) Warner-Bratzler shear evaluations of 40 bovine muscles *Meat Science* **64**, 507–512. doi:10.1016/S0309-1740(02)00242-5.

Belk KE, Scanga JA (2004) Slaughter-line operation: cattle. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 1237–1242. Elsevier, Oxford.

Bell BW, Dolezal HG, Grose DJ (2005) Method and apparatus for tenderizing meat. US2005/0221746.

Bendall JR (1969) *Muscles, Molecules, and Movement*. Heinemann, London.

Bickerstaffe R, Bekhit AED, Robertson LJ, Roberts N, Geesink GH (2001) Impact of introductory specifications on the tenderness of retail meat. *Meat Science* **59**, 303–315. doi:10.1016/S0309-1740(01)00083-3.

Bond MP (1984) Commercial trails of beef carcase classification in Western Australia. *Proceedings of the 15th Biennial Conference of the Australian Society of Animal Production*, pp. 43–45, Perth.

Borggaard C, Madsen NT, Thodberg HH (1996) In-line image analysis in the slaughter industry, illustrated by beef carcass classification. *Meat Science* **43**, 151–163. doi:10.1016/0309-1740(96)00062-9.

Bouton PE, Harris PV (1972) The effects of some post-slaughter treatments on the mechanical properties of bovine and ovine muscle. *Journal of Food Science* **37**, 539–543. doi:10.1111/j.1365-2621.1972.tb02687.x.

Bouton PE, Carroll FD, Fisher AL, Harris PV, Shorthose WR (1973a) Effect of altering ultimate pH on bovine muscle tenderness. *Journal of Food Science* **38**, 816–820. doi:10.1111/j.1365-2621.1973.tb02083.x.

Bouton PE, Fisher AL, Harris PV, Baxter RI (1973b) A comparison of the effects of some post-slaughter treatments on the tenderness of beef. *Journal of Food Technology* **8**, 39–49. doi:10.1111/j.1365-2621.1973.tb01687.x.

Brereton N, Treffone G, Gutzke D (2011) Commercial proving of spray chilling in Australian beef plants – Phase 2. Final Report Project P.PIP.0228. Meat & Livestock Australia.

Brownlie LE, Grau FH (1967) Effect of food intake on growth and survival of salmonellas and *Escherichia coli* in the bovine rumen *Journal of General Microbiology* **46**, 125–134. doi:10.1099/00221287-46-1-125.

Cafe LM, Robinson DL, Ferguson DM, McIntyre BL, Geesink GH, Greenwood PL (2011) Cattle temperament: persistence of assessments and associations with productivity, efficiency, carcass and meat quality traits. *Journal of Animal Science* **89**, 1452–1465. doi:10.2527/jas.2010-3304.

Cannell RC, Tatum JD, Belk KE, Wise JW, Clayton RP, Smith GC (1999) Dual-component video image analysis (VIASCAN) as a predictor of beef carcass red meat yield percentage and for augmenting application of USDA yield grades. *Journal of Animal Science* **77**, 2942–2950.

Carpenter CE, Smith JV, Broadbent JR (2011) Efficacy of washing meat surfaces with 2% levulinic, acetic, or lactic acid for pathogen decontamination and residual growth inhibition. *Meat Science* **88**, 256–260. doi:10.1016/j.meatsci.2010.12.032.

Chrystall BB, Devine CE (1980) Electrical stimulation developments in New Zealand. In *Proceedings of the 26th European Meat Research Workers Conference*, pp. 104–107. Colorado Springs.

Claus JR, Wang H, Marriott NG (1997) Pre-rigor carcass muscle stretching effects on tenderness of grain-fed beef under commercial conditions. *Journal of Food Science* **62**, 1231–1234. doi:10.1111/j.1365-2621.1997.tb12251.x.

Colditz IG, Watson DL, Kilgour R, Ferguson DM, Prideaux C, Ruby J, Kirkland PD, Sullivan K (2006) Impact of animal health and welfare research within the CRC for Cattle and Beef Quality on Australian beef production. *Australian Journal of Experimental Agriculture* **46**, 233–244. doi:10.1071/EA05211.

Cole JW, Ramsey CB, Epley RH (1962) Simplified method for predicting pounds of lean in beef carcasses. *Journal of Animal Science* **21**, 355–361.

Cook CJ, Maasland SA, Devine CE, Gilbert KV, Blackmore DK (1996) Changes in the release of amino acid neurotransmitters in the brains of calves and sheep after head-only electrical stunning and throat cutting. *Research in Veterinary Science* **60**, 255–261. doi:10.1016/S0034-5288(96)90050-8.

Cross HR, Gilliland DA, Durland PR, Seideman S (1983) Beef carcass evaluation by use of a video image analysis system. *Journal of Animal Science* **57**, 908–917.

Crouse JD, Dikeman ME, Koch RM, Murphey CE (1975) Evaluation of traits in the USDA yield grade equation for predicting beef carcass cutability in breed groups differing in growth and fattening characteristics. *Journal of Animal Science* **41**, 548–553.

Davey CL, Gilbert KV, Carse WA (1976) Carcass electrical stimulation to prevent cold shortening toughness in beef. *New Zealand Journal of Agricultural Research* **19**, 13–18. doi:10.1080/00288233.1976.10421040.

de Boer H (1992) EC standards: carcass classification in Europe; history and actual position. *Meat Focus International* **1**, 365–368.

Devine CE, Graafhuis AE (1995) The basal tenderness of unaged lamb. *Meat Science* **39**, 285–291. doi:10.1016/0309-1740(94)P1829-K.

Devine CE, Tavener A, Gilbert KV, Day AM (1986) Electroencephalographic studies of adult cattle associated with electrical stunning, throat cutting and carcass electro-immobilization. *New Zealand Veterinary Journal* **34**, 210–213. doi:10.1080/00480169.1986.35352.

Devine CE, Bell RG, Lovatt SJ, Chrystall BB, Jeremiah LE (1996) Red meats. In *Freezing Effects on Food Quality*. (Ed. L. Jeremiah) pp. 51–84. Marcel Dekker, New York.

Devine CE, Hopkins DL, Hwang IH, Ferguson DM, Richards I (2004) Electrical stimulation. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 413–423. Elsevier, Oxford.

Dransfield E, Roncales P (1998) *Concerted Action CT94-1881. Very Fast Chilling in Beef. 2. Muscle to Meat*. University of Bristol Press, Bristol.

Egan AF, Shay BJ (1988) Long-term storage of chilled fresh meats. In *Proceedings of the 34th International Congress of Meat Science and Technology,* pp. 476–481, Brisbane.

Ferguson DM (1993). Objective evaluation of yield and meat-quality characteristics. In *Proceedings of the Australian Meat Industry Research Conference,* Session 4, pp. 1–8. Gold Coast, Australia.

Ferguson DM, Warner RD (2008) Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? *Meat Science* **80**, 12–19. doi:10.1016/j.meatsci.2008.05.004.

Ferguson DM, Thompson JM, Barrett-Lennard D, Sorensen B (1995). Prediction of beef carcass yield using whole carcass VIAscan®. In *Proceedings of the 41st International Congress of Meat Science and Technology,* pp 183–184, San Antonio.

Ferguson DM, Bruce HL, Thompson JM, Egan AF, Perry D, Shorthose WR (2001) Factors affecting beef palatability: farmgate to chilled carcass. *Australian Journal of Experimental Agriculture* **41**, 879–891. doi:10.1071/EA00022.

Fisher AD, Colditz IG, Lee C, Ferguson DM (2009) The influence of land transport on animal welfare in extensive farming systems. *Journal of Veterinary Behavior* **4**, 157–162. doi:10.1016/j.jveb.2009.03.002.

Fordyce G, Wythes JR, Shortjose WR, Underwood DW, Shepherd RK (1988) Cattle temperaments in extensive beef herds in northern Queensland. 2. Effect of temperament on carcass and meat quality. *Australian Journal of Experimental Agriculture* **28**, 689–693. doi:10.1071/EA9880689.

Frazer AE (1997) New Zealand tenderness and local meat quality mark programmes In *Proceedings of Meat Quality and Technology Transfer Workshops*, pp. 37–47, Auckland.

Gardner MA, Schaefer DL, Claus J, McKenna DR (2007) Meat tenderization methods and systems. US2007/0254579.

Geesink G, Thompson J (2008) Utilising the 'Boa' stretching technology to improve the quality of hot boned striploins. Report No. RE-221941. School of Environmental and Rural Science, University of New England, Armidale.

George MH, Tatum JD, Belk KE, Smith GC (1999) An audit of retail beef loin steak tenderness conducted in eight U.S. cities. *Journal of Animal Science* **77**, 1735–1741.

Grandin T (1993) Teaching principles of behavior and equipment design for handling livestock. *Journal of Animal Science* **71**, 1065–1070.

Grandin T (2001) Livestock-handling quality assurance. *Journal of Animal Science* **79**, E239–E248.

Grandin T (2010) Auditing animal welfare at slaughter plants. *Meat Science* **86**, 56–65. doi:10.1016/j.meatsci.2010.04.022.

Grandin T (2011) *Tips to Improve Animal Movement into Conveyor Restrainers, Stunning Boxes and Squeeze Chutes*. <http://grandin.com/restrain/improve.mvmt.html>.

Gregory NG (2005) Recent concerns about stunning and slaughter: a review. *Meat Science* **70**, 481–491. doi:10.1016/j.meatsci.2004.06.026.

Gregory NG, Jacobson LH, Nagle TA, Muirhead RW, Leroux GJ (2000) Effect of pre-slaughter feeding system on weight loss, gut bacteria, and the physico-chemical properties of digesta in cattle. *New Zealand Journal of Agricultural Research* **43**, 351–361. doi:10.1080/00288233.2000.9513434.

Gregory NG, Lee CJ, Widdicombe JP (2007) Depth of concussion in cattle shot by penetrating captive bolt. *Meat Science* **77**, 499–503. doi:10.1016/j.meatsci.2007.04.026.

Hemsworth PH, Rice M, Karlen MG, Calleja L, Barnett JL, Nash J, Coleman GJ (2011) Human–animal interactions at abattoirs: relationships between handling and animal stress in sheep and cattle. *Applied Animal Behaviour Science* **135**, 24–33. doi:10.1016/j.applanim.2011.09.007.

Hogan JP, Petherick JC, Phillips CJC (2007) The physiological and metabolic impacts on sheep and cattle of feed and water deprivation before and during transport. *Nutrition Research Reviews* **20**, 17–28. doi:10.1017/S0954422407745006.

Hopkins DL (1989a) Reliability of three sites for measuring fat depth on the beef carcass. *Australian Journal of Experimental Agriculture* **29**, 165–168. doi:10.1071/EA9890165.

Hopkins DL (1989b) An evaluation of the Hennessy Grading Probe for measuring fat depth in beef carcasses. *Australian Journal of Experimental Agriculture* **29**, 781–784. doi:10.1071/EA9890781.

Hopkins DL (2004) Tenderising mechanisms: mechanical. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman), pp. 1355–1363. Elsevier, Oxford.

Hopkins DL, Geesink GH (2009) Protein degradation post mortem and tenderisation. In *Applied Muscle Biology and Meat Science*. (Ed M Du and R McCormick) pp. 149–173. CRC Press, Boca Raton.

Hopkins DL, Roberts AHK (1993) Australian grass-fed beef for Japan. 1. Carcass quality characteristics, saleable meat yield and the value of various carcass measurements for predicting yield. *Australian Journal of Experimental Agriculture* **33**, 685–691. doi:10.1071/EA9930685.

Hopkins DL, Thompson JM (2002) Factors contributing to proteolysis and disruption of myofibrillar proteins and the impact on tenderisation in beef and sheep meat. *Australian Journal of Agricultural Research* **53**, 149–166. doi:10.1071/AR01079.

Hopkins DL, Littlefield PJ, Thompson JM (2000) The effect on tenderness of super tenderstretching. *Asian-Australasian Journal of Animal Science* **13**(Suppl. C), 240

Hopkins DL, Shaw FD, Baud S, Walker PJ (2006) Electrical currents applied to lamb carcases: effects on blood release and meat quality. *Australian Journal of Experimental Agriculture* **46**, 885–889. doi:10.1071/EA05310.

Hopkins DL, Cassar JA, Toohey ES, Wynn PC (2007) Examination of pH in lot fed beef for Japan. In *Proceedings of the 67th New Zealand Society of Animal Production*, pp. 436–440, Wanka, New Zealand.

Hopkins DL, Toohey ES, Kerr MJ, van de Ven R (2011) Comparison of the G2 Tenderometer and the Lloyd Texture Analyser for measuring shear force in sheep and beef meats. *Animal Production Science* **51**, 71–76. doi:10.1071/AN10136.

Hopkins DL, Warner RD, Ponnampalam EN, van de Ven RJ (2013) The effect of fast pH decline on the meat and eating quality of beef carcases. *Animal Production Science.* (In press).

Hostetler RL, Landmann WA, Link BA, Fitzhugh HA Jr (1970) Influence of carcass position during *rigor mortis* on tenderness of beef muscles: comparison of two treatments. *Journal of Animal Science* **31**, 47–50.

Hubbard JI (1973) Microphysiology of vertebrate neuromuscular transmission *Physiology Reviews* **53**, 674–723.

Huff-Lonergan E, Lonergan SM (2005) Mechanisms of water-holding capacity of meat: the role of postmortem biochemical and structural changes. *Meat Science* **71**, 194–204. doi:10.1016/j.meatsci.2005.04.022.

Hwang IH, Thompson JM (2001a) The interaction between pH and temperature decline early postmortem on the calpain system and objective tenderness in electrically stimulated beef longissimus dorsi muscle. *Meat Science* **58**, 167–174. doi:10.1016/S0309-1740(00)00147-9.

Hwang IH, Thompson JM (2001b) The effect of time and type of electrical stimulation on the calpain system and meat tenderness in beef longissimus dorsi muscle. *Meat Science* **58**, 135–144. doi:10.1016/S0309-1740(00)00141-8.

Hwang IH, Devine CE, Hopkins DL (2003) Review: the biochemical and physical effects of electrical stimulation on beef and sheep tenderness. *Meat Science* **65**, 677–691. doi:10.1016/S0309-1740(02)00271-1.

Jacob RH, Hopkins DL (2013) Techniques to reduce the temperature of beef muscle early in the post mortem period: a review. *Animal Production Science.* (In press).

Jeacocke RE (1984) The kinetics of *rigor* onset in beef muscle fibres. *Meat Science* **11**, 237–251. doi:10.1016/0309-1740(84)90055-X.

Jeremiah LE, Schaefer AL, Gibson LL (1992) The effects of ante-mortem feed and water withdrawal, ante-mortem electrolyte supplementation, and post-mortem electrical stimulation on the palatability and consumer acceptance of bull beef after ageing (6 days at 1°C). *Meat Science* **32**, 149–160. doi:10.1016/0309-1740(92)90102-A.

Johnson ER, Vidyadaran MK (1981) An evaluation of different sites for measuring fat thickness in the beef carcass to determine carcass fatness. *Australian Journal of Agricultural Research* **32**, 999–1007. doi:10.1071/AR9810999.

Jones SDM, Richmond RJ, Robertson WM (1995) Meat grading: instrument beef grading. *Meat Focus International* **4**, 59–62.

Jones SJ, Calkins CR, Johnson DD, Gwartney BL (2005) *Bovine Mycology*. University of Nebraska. <http://bovine.unl.edu>.

Joseph RL (1996) Very fast chilling of beef and tenderness: a report from an EU concerted action. *Meat Science* **43**, 217–227. doi:10.1016/0309-1740(96)00067-8.

King DA, Schuehle Pfeiffer CE, Randel RD, Welsh TH, Oliphant RA, Baird BE, Curley KO, Vann DR, Hale CS, Savell JW (2006) Influence of animal temperament and stress responsiveness on the carcass quality and beef tenderness of feedlot cattle *Meat Science* **74**, 546–556. doi:10.1016/j.meatsci.2006.05.004.

Koohmaraie M (1996) Biochemical factors regulating the toughening and tenderization processes of meat. *Meat Science* **43**(Suppl.), 193–201. doi:10.1016/0309-1740(96)00065-4.

Koutsoumanis K, Sofos JN (2004) Microbial contamination. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 727–737. Elsevier, Oxford.

Lambooji E (2004) Stunning/electrical. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 1342–1348. Elsevier, Oxford.

Locker RH, Hagyard CJ (1963) A cold shortening effect in beef muscles *Journal of the Science of Food and Agriculture* **14**, 787–793. doi:10.1002/jsfa.2740141103.

Lovatt SJ (2004) Refrigeration and freezing technology/applications. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 1137–1143. Elsevier, Oxford.

Ludwig CJ, Claus JR, Marriott NG, Johnson J, Wang H (1997) Skeletal alteration to improve beef *longissimus* muscle tenderness. *Journal of Animal Science* **75**, 2404–2410.

McDonnell DA (2003) Cattle slaughtering and meat treatment. IE20020230.

McGilchrist P, Café LM, Pethick DW, Greenwood PL, Gardner GE (2011) Cattle with more reactive temperaments have lower resting muscle glycogen In *Proceedings of the 57th International Congress of Meat Science and Technology,* P008, pp. 1–4, Ghent.

McGilchrist P, Alston CL, Gardner GE, Thomson KL, Pethick DW (2012) Beef carcasses with larger eye muscle areas, lower ossification scores and improved nutrition have a lower incidence of dark cutting. *Meat Science* **92**, 474–480. doi:10.1016/j.meatsci.2012.05.014.

McMillin KW (2008) Where is MAP going? A review and future potential of modified atmosphere packaging in meat *Meat Science* **80**, 43–65. doi:10.1016/j.meatsci.2008.05.028.

McPhail NG (1995) Implementation of hot boning In *Meat 95, The Australian Meat Industry Research Conference*, pp. 5–6. 10–12 September, Gold Coast, Australia.

Miller MF, Carr MA, Ramsey CB, Crockett KL, Hoover LC (2001) Consumer thresholds for establishing the value of beef tenderness. *Journal of Animal Science* **79**, 3062–3068.

MSA (2010) *What next for MSA?* <http://www.mla.com.au/files/00674356-2089-430e-bfdc-9e33010516ca/mla-producer-forum-2010-michellegorman.pdf> and *MSA Beef brochure* <http://www.mla.com.au/files/1ecd5a95-a823-4af4-b14b-9d5f007f9d59/msa-beef-brochure.pdf>.

Muchenje V, Dzama K, Chimoyo M, Strydom PE, Raats JG (2009) Relationship between pre-slaughter stress responsiveness and beef quality in three cattle breeds *Meat Science* **81**, 653–657. doi:10.1016/j.meatsci.2008.11.004.

Newton KG, Gill CO (1981) The microbiology of DFD fresh meats: a review *Meat Science* **5**, 223–232. doi:10.1016/0309-1740(81)90005-X.

Ngapo TM, Babare IH, Reynolds J, Mawson RF (1999) A preliminary investigation of the effects of frozen storage on samples of pork *Meat Science* **53**, 169–177. doi:10.1016/S0309-1740(99)00052-2.

O'Sullivan A, Korzeniowska M, White A, Troy DJ (2003) Using a novel intervention technique to reduce the variability and improve tenderness of beef *longissimus dorsi*. In *Proceedings of the 49th International Congress of Meat Science and Technology,* pp. 513–514, Campinas, Brazil.

Ouali A, Hernan-Mendez CH, Coulis G, Beclia S, Boudjellal A, Aubury L, Sentandreu MA (2006) Revisting the conversion of muscle into meat and the underlying mechanisms. *Meat Science* **74**, 44–58. doi:10.1016/j.meatsci.2006.05.010.

Pabiou T, Berry DP (2009). Prediction of beef meat cuts using video image analysis in Ireland. In *Proceedings of the 60th EAAP conference*, p. 145, Barcelona.

Park BY, Hwang IH, Cho SH, Yoo YM, Kim JH, Lee JM, Polkinghorne R, Thompson JM (2008) Effect of carcass suspension and cooking method on the palatability of three beef muscles as assessed by Korean and Australian consumers. *Australian Journal of Experimental Agriculture 48*, 1396–1404.

Pearce KL, Jacob RH, Masters DG, Hopkins DL, Pethick DW (2008) The effects of sodium chloride and betaine on the hydration status of lambs at slaughter. *Australian Journal of Experimental Agriculture* **48**, 1194–1200. doi:10.1071/EA08034.

Perry D, Thompson JM, Hwang IH, Butchers A, Egan A (2001) Relationship between objective measurements and taste panel assessment of beef quality. *Australian Journal of Experimental Agriculture* **41**, 981–989. doi:10.1071/EA00023.

Petherick JC, Holroyd RG, Doogan VJ, Venus BK (2002) Productivity, carcass and meat quality of lot-fed *Bos indicus* cross steers grouped according to temperament. *Australian Journal of Experimental Agriculture* **42**, 389–398. doi:10.1071/EA01084.

Phillips D, Herrod W, Schafer RJ (1987) The measurement of subcutaneous fat depth on hot beef carcasses with the Hennessy Grading Probe. *Australian Journal of Experimental Agriculture* **27**, 335–338. doi:10.1071/EA9870335.

Phillips G, Ridley PER, Horcicka JV (1982). Trading by specification: the effect of backfat depth on the pricing of beef cattle at an abattoir. In *Proceedings of the 14th Biennial Conference of the Australian Society of Animal Production,* pp. 361–364.

Pisula A, Tyburcy A (1996) Hot processing of meat. *Meat Science* **43**, 125–134. doi:10.1016/0309-1740(96)00060-5.

Pitt A, Daly CC (2008). Meat stretching device and method. WO2008/123782.

Polkinghorne RJ (2006) Implementing palatability assured critical control point (PACCP) approach to satisfy consumer demands. *Meat Science* **74**, 180–187. doi:10.1016/j.meatsci.2006.05.001.

Polkinghorne R, Philpot J, Gee A, Doljanin A, Innes J (2008a) Development of a commercial system to apply the Meat Standards Australia grading model to optimise the return on eating quality in a beef supply chain. *Australian Journal of Experimental Agriculture* **48**, 1451–1458. doi:10.1071/EA05181.

Polkinghorne R, Thompson JM, Watson R, Gee A, Porter M (2008b) Evolution of the Meat Standards Australia (MSA) beef grading system. *Australian Journal of Experimental Agriculture* **48**, 1351–1359. doi:10.1071/EA07177.

Powell L, Nicholson KL, Huerta-Montauti D, Miller RK, Savell JW (2011) Constraints on establishing threshold levels for Warner-Bratzler shear-force values based on consumer sensory ratings for seven beef muscles. *Animal Production Science* **51**, 959–966. doi:10.1071/AN10267.

Purchas RW, Yan X, Hartley DG (1999) The influence of a period of ageing on the relationship between ultimate pH and shear values of beef *m. longissimus thoracis Meat Science* **51**, 135–141. doi:10.1016/S0309-1740(98)00111-9.

Rekow CL, Brashears MM, Brooks JC, Loneragan GH, Gragg SE, Miller MF (2011) Implementation of targeted interventions to control *Escherichia coli* O157:H7 in a commercial abattoir. *Meat Science* **87**, 361–365. doi:10.1016/j.meatsci.2010.11.012.

Reverter A, Johnston DJ, Ferguson DM, Perry D, Goddard ME, Burrow HM, Oddy VH, Thompson JM, Bindon BM (2003) Genetic and phenotypic characterisation of animal, carcass, and meat quality traits from temperate and tropically adapted beef breeds. 4. Correlations among animal, carcass, and meat quality traits. *Australian Journal of Agricultural Research* **54**, 149–158. doi:10.1071/AR02088.

Rhee MS, Wheeler TL, Shackelford TL, Koohmaraie M (2004) Variation in palatability and biochemical traits within and among eleven beef muscles. *Journal of Animal Science* **82**, 534–550.

Rosenvold K, North M, Devine C, Micklander E, Hansen P, Dobbie P, Wells R (2008) The protective effect of electrical stimulation and wrapping on beef tenderness at high pre-rigor temperatures. *Meat Science* **79**, 299–306. doi:10.1016/j.meatsci.2007.10.002.

Ross T, Ratkowsky DA, Mellefont LA, McMeekin TA (2003) Modelling the effects of temperature, water activity, pH and lactic acid concentration on the growth rate of *Escherichia coli*. *International Journal of Food Microbiology* **82**, 33–43. doi:10.1016/S0168-1605(02)00252-0.

Schaefer AL, Jones SDM, Tong AKW, Young BA (1990) Effects of transport and electrolyte supplementation on ion concentrations, carcase yield and quality in bulls. *Canadian Journal of Animal Science* **70**, 107–119. doi:10.4141/cjas90-012.

Schaefer AL, Jones SDM, Tong AKW, Young BA, Murray NL, Lepage P (1992) Effects of post-transport electrolyte supplementation on tissue electrolytes, hematology, urine osmolality and weight loss in beef bulls. *Livestock Production Science* **30**, 333–346. doi:10.1016/0301-6226(92)90042-3.

Shanks BC, Wulf DM, Reuter BJ, Maddock RJ (2002) Increasing tenderness of beef round and sirloin muscles through prerigor skeletal separations. *Journal of Animal Science* **80**, 123–128.

Sheridan JJ (1998) Sources of contamination during slaughter and measures for control. *Journal of Food Safety* **18**, 321–339. doi:10.1111/j.1745-4565.1998.tb00223.x.

Shorthose WR, Harris PV (1990) Effect of animal age on the tenderness of selected beef muscles. *Journal of Food Science* **55**, 1–8. doi:10.1111/j.1365-2621.1990.tb06004.x.

Shorthose WR, Wythes JR (1988) Transport of sheep and cattle. In *Proceedings of the 34th International Congress of Meat Science and Technology,* pp. 122–129, Brisbane.

Shragge JE, Price MA (2004) Religious slaughter. In *Encyclopedia of Meat Sciences*. (Eds W Jensen, C Devine and M Dikeman) pp. 1162–1167. Elsevier, Oxford.

Simmons NJ, Cairney JM, Auld MM, Nagle TA, Mudford CR (1999) Effect of pre-rigor stretching of beef *m. Longissumus thoracis* muscles on structural changes and key meat quality attributes. In *Proceedings of the 45th International Congress of Meat Science and Technology,* 1–6 August, Yokohama.

Smith DR, Smith NB, Muir PD (1999) Farm of origin and finishing environment effects on beef quality attributes. *Proceedings of the New Zealand Society of Animal Production* **59**, 282–286.

Smith GC, Tatum JD, Belk KE (2008) International perspective: characterization of United States Department of Agriculture and Meat Standards Australia systems for assessing beef quality. *Australian Journal of Experimental Agriculture* **48**, 1465–1480. doi:10.1071/EA08198.

Sofos JN (2008) Challenges to meat safety in the 21st century. *Meat Science* **78**, 3–13. doi:10.1016/j.meatsci.2007.07.027.

Sørheim O, Hildrum KI (2002) Muscle stretching techniques for improving meat tenderness. *Trends in Food Science and Technology* **13**, 127–135. doi:10.1016/S0924-2244(02)00069-9.

Sørheim O, Idland J, Halvorsen EC, Frøystein T, Lea P, Hildrum KI (2001) Influence of beef carcass stretching and chilling rate on tenderness of *m. Longissimus dorsi. Meat Science* **57**, 79–85. doi:10.1016/S0309-1740(00)00079-6.

South RD (1995) Oxygen-free, carbon dioxide rich, modified atmosphere packaging. In *Proceedings of the Australian Meat Industry Research Conference*, pp. 10.1–10.4, Gold Coast, Australia.

Spooncer WF (1993) Options for hot boning. In *Meat 93, The Australian MeatIindustry Research Conference*, pp. 1–6, Gold Coast, Australia.

Stetzer AJ, Cadwallader K, Singh TK, Mckeith FK, Brewer MS (2008) Effect of enhancement and ageing on flavour and volatile compounds in various beef muscles. *Meat Science* **79**, 13–19. doi:10.1016/j.meatsci.2007.07.025.

Strydom PE, Frylinck L, Smith MF (2005) Should electrical stimulation be applied when cold shortening is not at risk? *Meat Science* **70**, 733–742. doi:10.1016/j.meatsci.2005.03.010.

Tarrant PV (1989) Animal behaviour and environment in the dark-cutting condition in beef: a review. *International Journal of Food Science and Technology* **13**, 1–21.

Taylor JM, Hopkins DL (2011) Patents for stretching and shaping meats. *Recent Patents on Food, Nutrition and Agriculture* **3**, 91–101.

Taylor JM, Hopkins DL, van de Ven R (2010) The effect of a meat stretching device on the tenderness of hot-boned beef topsides and rostbiffs. In *Proceedings of the 56th International Congress of Meat Science and Technology,* Session E, Paper E069, pp. 1–4, 15–20 August, Jeju, Korea.

Taylor JM, Toohey ES, van de Ven R, Hopkins DL (2012) SmartStretch™ technology. IV. The impact on the meat quality of hot-boned beef *m gluteus medius. Meat Science* **91**, 527–532. doi:10.1016/j.meatsci.2012.03.009.

Templer R (2004) Robotics and new technology. In *Encyclopedia of Meat Sciences.* (Eds W Jensen, C Devine and M Dikeman) pp. 381–388. Elsevier, Oxford.

Thompson JM (2002) Managing meat tenderness. *Meat Science* **62**, 295–308. doi:10.1016/S0309-1740(02)00126-2.

Toohey ES, Kerr MJ, van de Ven R, Hopkins DL (2010) The effect of smartstretch technology on the tenderness of beef topsides and cube rolls. In *Proceedings of the 56th International Congress of Meat Science and Technology,* Session E, Paper E072, pp. 1–4, 15–20 August, Jeju, Korea.

Troy DJ (2006) Hot-boning of meat: a new perspective. In *Advanced Technologies for Meat Processing.* (Eds LML Nollet and F Toldra) pp. 74–83. CRC Press, Boca Raton.

Troy DJ, Kerry JP (2010) Consumer perception and the role of science in the meat industry. *Meat Science* **86**, 214–226. doi:10.1016/j.meatsci.2010.05.009.

Truscott T (1988) Some observations of dark-cutting beef in Victoria. In *Dark-cutting in Cattle and Sheep: Proceedings of an Australian Workshop.* (Eds SV Fabiansson, WR Shorthose and RD Warner) p. 91. AMLRDC, Sydney.

USDA/FSIS (2011) *Safe and Suitable Ingredients used in the Production of Meat, Poultry, and Egg Products.* FSIS Directive 7120.1 Revision 9. <http://www.fsis.usda.gov/OPPDE/rdad/FSISDirectives/7120.1.pdf>.

Vanselow BA, Hornitzky MA, Walker KH, Eamens GJ, Bailey GD, Gill PA, Coates K, Corney B, Cronin JP, Renilson S (2007) Salmonella and on-farm risk factors in healthy slaughter-age cattle and sheep in eastern Australia. *Australian Veterinary Journal* **85**, 498–502. doi:10.1111/j.1751-0813.2007.00233.x.

Voisinet BD, Grandin T, O'Connor SF, Tatum JD, Deesing MJ (1997) *Bos indicus*-cross feedlot cattle with excitable temperaments have tougher meat and a higher incidence of borderline dark cutters. *Meat Science* **46**, 367–377. doi:10.1016/S0309-1740(97)00031-4.

Von Seggern DD, Calkins CR, Johnson DD, Brickler JE, Gwartney BL (2005) Muscle profiling: characterizing the muscles of the beef chuck and round. *Meat Science* **71**, 39–51. doi:10.1016/j.meatsci.2005.04.010.

Wang H, Claus JR, Marriott NG (1996) Pre-rigor treatment and endpoint temperature effects on US Choice beef tenderness. *Journal of Muscle Foods* **7**, 45–54. doi:10.1111/j.1745-4573.1996.tb00586.x.

Warner RD (2010) Optimising the abattoir component of the supply chain for red meat to increase processing efficiency, yield and quality. Final Report A.MQT.029. Meat & Livestock Australia, Sydney.

Warner RD, Truscott TG, Eldridge GA, Franz PR (1988) A survey of the incidence of high pH beef meat in Victorian abattoirs. In *Proceedings of the 34th International Congress of Meat Science and Technology,* pp. 150–151, Brisbane.

Warner RD, Ferguson DM, Cottrell JJ, Knee BW (2007) Acute stress induced by the preslaughter use of electric prodders causes tougher beef meat. *Australian Journal of Experimental Agriculture* **47**, 782–788. doi:10.1071/EA05155.

Warner RD, Thompson JM, Polkinghorne R, Gutzke D, Kearney GA (2013) A consumer sensory study of the influence of rigor temperature on eating quality and ageing potential of beef striploin and rump. *Animal Production Science.* (In press).

Warriss PD (1990) The handling of cattle pre-slaughter and its effects on carcass and meat quality *Applied Animal Behaviour Science* **28**, 171–186. doi:10.1016/0168-1591(90)90052-F.

Watson R, Polkinghorne R, Thompson JM (2008) Development of the Meat Standards Australia (MSA) prediction model for beef palatability. *Australian Journal of Experimental Agriculture* **48**, 1368–1379. doi:10.1071/EA07184.

Widders PR, Coates KJ, Warner S, Beattie JC, Morgan IR, Hickey MW (1995) Controlling microbial contamination on beef and lamb meat during processing *Australian Veterinary Journal* **72**, 208–211. doi:10.1111/j.1751-0813.1995.tb03521.x.

Wold JP, O'Farrell M, Høy M, Tschudi J (2011) On-line determination and control of fat content in batches of beef trimmings by NIR imaging spectroscopy. *Meat Science* **89**, 317–324. doi:10.1016/j.meatsci.2011.05.001.

Wotton SB, Gregory NG, Whittington PE, Parkman ID (2000) Electrical stunning of cattle. *Veterinary Record* **147**, 681–684.

Wythes JR, Tyler R, Daly JJ, Burns MA, Llewelyn D (1981a) Effect of various feed and water regimens at saleyards on the liveweight of store cattle. *Australian Journal of Experimental Agriculture and Animal Husbandry* **21**, 553–556. doi:10.1071/EA9810553.

Wythes JR, Arthur RJ, Thompson PJM, Williams GE, Bond JH (1981b) Effect of transporting cows various distances on liveweight, carcase traits and muscle pH. *Australian Journal of Experimental Agriculture and Animal Husbandry* **21**, 557–561. doi:10.1071/EA9810557.

Zakrys PI, Hogan SA, O'Sullivan MG, Allen P, Kerry JP (2008) Effects of oxygen concentration on the sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. *Meat Science* **79**, 648–655. doi:10.1016/j.meatsci.2007.10.030.

Zakrys PI, O'Sullivan MG, Allen P, Kerry JP (2009) Consumer acceptability and physiochemical characteristics of modified atmosphere packed beef steaks. *Meat Science* **81**, 720–725. doi:10.1016/j.meatsci.2008.10.024.

3 Market preparation

R. Mulley, I. Lean and V.E. Wright

INTRODUCTION

Correct market identification and astute management of a beef enterprise to achieve targeted market specifications or tactically attain other markets is pivotal to profitability (Chapter 18). Supplying cattle, carcasses and, ultimately, specific cuts that meet market specifications of domestic and international customers is crucial in ensuring that export-focused nations, such as Australia, remain competitive in the international marketplace (Andrews and Littler 2007).

Enterprise planning begins with the objective of producing a commodity that matches market requirements. One or more markets may be targeted in a business plan to allow for flexible production systems. This chapter covers the beef value chain, market specifications for beef, selection strategies for specific markets, prediction modelling for optimal growth and development, finishing animals to meet market specifications, and ideas for on-farm value-adding.

THE AUSTRALIAN BEEF VALUE CHAIN

Value chains, also called supply chains, comprise the individuals and organisations that create the products offered to final consumers. This chain includes all entities that play a role in creating the final form of the tangible good or intangible service, or combination of both, which is the product, as well as those who distribute and promote it.

The 'supply chain' label emphasises the flow of the product from first-level producer to consumer: a technical or physical view. 'Value chain' also maps this flow but, importantly, embeds the idea that all activities and decisions made in the chain contribute to the value that the final consumer judges the offered product to have. Value chain is also used in the Strategic Management literature to refer to the value creation processes within a single enterprise (Porter 1985). This is a very different notion from the one used here.

This construct has some major implications. One is that product value will determine final product sales levels and revenue and, as a result, sales levels and prices everywhere through the value chain. Another is that product value for consumers is determined by the chain and not by any single member and, therefore, each member's revenue will be determined by their contribution to the final value. A required assumption is that markets are 'contestable': that one member's power in the chain does not permit them to extract a higher price for their contribution to final value than it is worth to the consumer. A principal role of the Australian Competition and Consumer Commission is to maintain contestability in markets.

Value chains can be identified at different scales: a value chain can relate to any level of aggregation of producers between a single producer and an entire product-defined sector, such as the beef value chain. The scale relevant here is sectoral, because our interest is in using the beef value chain as the basis for on-farm decisions that will relate farm capabilities to market possibilities. This process involves analysing customers that may be targeted, given the beef output capabilities of a farm or group of farms. The beef value chain is, therefore, a summary term for all the specific, different value chains used to transform beef into meat products offered to domestic and export consumers.

Consumers differ in their needs and preferences as well as their capacity to purchase products. This creates the possibility for consumers to be aggregated into 'market segments': groups of consumers with shared preferences for beef offers. Some will be large segments, others small. Some will be low-volume/high-margin, others high-volume/low-margin. Attitudes to eating quality, animal welfare, beef breed and a range of other matters may define segments. Segments may be defined by where they prefer to shop for beef. Segments may have no influence over the beef they are served: prisoners, hospital patients, restaurant patrons and residential college students are beef consumers, but not usually the beef customer.

The variety of segments in the market for Australian beef, which includes export segments, inevitably causes different specific paths through the value chain to be used by producers targeting them. Final consumers may not be the appropriate customer for a beef producer to target. The customer a beef producer should target will vary depending on the final market segment specific beef is sold to. The customer of interest to a beef producer supplying segments that purchase at supermarkets is the supermarket itself. The customer of interest at a farmers' market is the final consumer.

Beef producers need to consider how the beef they produce meets the preferences of consumer market segments that exist and, beyond that, how 'far' down the value chain they feasibly influence customer response to their output. This customer is the one whose preferences should be targeted.

A broad outline of the Australian beef value chain appears in Fig. 3.1. This identifies the major selling options facing beef farms. It does not identify every function that occurs in the chain. For instance, transportation occurs whenever transfer of animals or meat occurs between participants in the chain.

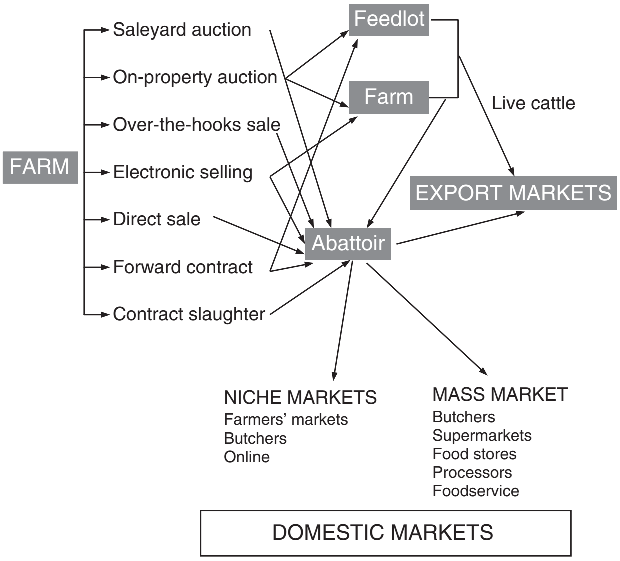


Figure 3.1: The Australian beef value chain. Source: Adapted from Cox *et al.* (2003, p. 89).

Common selling options for producers

Methods for sale of cattle have evolved between 1990 and 2009 (ABARE 2010), with an increasing percentage of cattle being sold in the paddock and fewer at auction. Examination of the top 25% of producers (based on rates of return exclusive of capital appreciation) shows a markedly lower reliance on auction than for producers in the lower categories of profitability. The main options can be grouped as follows.

Local saleyards and auctions

Most large rural towns and service centres in Australia have saleyards for livestock where local producers can sell cattle on a regular basis. This form of livestock selling dominates the southern Australian beef industry, though for northern Australian producers, over the hook selling dominates the market (ABARE 2010). The local saleyard provides a selling point for both large and small producers, and a buying point for all levels of industry including commercial enterprise restocking, feedlot stock, store cattle trading, local butcher shops, regional abattoirs and lifestyle farmers. Local saleyard transactions are 'buyer beware' and can mask genetic defects, infertile freemartin heifers (Chapter 14), chronic reproductive failure, disease status of traded animals, carcass bruising from careless yarding and transport, and many other production-limiting imperfections. Auctions can be conducted electronically and sell cattle that are in the paddock or elsewhere.

If buyers have local knowledge this may assist with background information on some of the stock traded on a particular day, but for most transactions, buyers will have relatively little background information on the stock they are purchasing. However, National Vendor Declaration Forms (NVDFs) and Weigh-bill accompany all cattle sold in Australia (MLA 2013a). The NVDFs provide information that is useful to the purchaser including details of the identity of the cattle (National Livestock Identification Ear Tags or Rumen Device Numbers) and length of time that the cattle were owned by the vendor. Some sales require provision of a cattle health declaration that addresses endemic diseases, many of which are subject to control programs, e.g. Johne's disease, cattle tick (Anonymous 2012). Details relevant to the background management are also provided, such as whether the cattle have been treated with hormonal hrowth promotants (HGP) and whether they have been fed by-product feeds and animal fats. Risks of exposure of the cattle to veterinary and agricultural chemicals are also addressed, including recent drug treatments involving withholding periods. The pregnancy status of cattle can be identified using information provided by the National Pregnancy Diagnosis scheme of the Australian Cattle Veterinarians. Cattle are identified using a tail tag that is single-use only. The most common tags are red and yellow, which indicates cattle more than 4 months pregnant, blue and orange for less than 4 months, and green and white tags for cattle not detectably pregnant. Each tag bears a serial number and a veterinarian identification code. The scheme is tested by periodic examination of veterinarians and provides a quality-assured method of validating the status of cattle. An astute buyer will use these sources of information, and local knowledge, to make more informed purchases of cattle.

Contract growing

Contract growing refers to forward selling contracts negotiated between a cattle producer and a buyer. Contracts are most frequently established with producers to supply feeder stock to feedlots, butchers or large supermarket chains. Other areas of the cattle industry where contract growing of stock occurs include supply of replacement breeding heifers to the beef industry, replacement heifers to the dairy industry, breeding bulls to beef cattle producers, and weaner stock to cattle traders who opportunistically react to market trends. The advantages of contract selling for producers include market certainty, known pricing for animals that meet the agreed characteristics, and a reduction in variable costs associated with other forms of selling such as transport costs and auction levies. The disadvantages for producers include being locked in to a price that may disadvantage them if market prices increase, and penalties for not being able to produce the contracted number of animals with the required characteristics in the production period. Contracts usually stipulate the number of animals required, the weight, age and body condition score or fat depth at the P8 site. The advantages of contract growing for buyers include certainty over supply of stock, quality of stock sourced, and an opportunity to work more closely with producers to manage growth of animals to more closely match their requirements.

Figure 3.2: Cattle being raised in a commercial feedlot. Source: I.J. Lean, SBScibus.

Feedlots frequently buy feeder stock from contract growers (Fig. 3.2), where breed type, genetic background, husbandry practices, level of stockmanship and performance recording are known. Contract growers usually enter into formal agreements with feedlots to produce cattle with specified characteristics, and work closely in partnership with one or more feedlots to accommodate short- and long-term markets. Not all cattle produced by contract growers meet the required specifications for growth, size and body condition required by feedlots, and cattle that do not meet specifications are usually sold through local saleyards for domestic consumption. These cattle usually meet the criteria for light/medium-weight steers and heifers suitable for the butcher shop trade.

Cattle raised on forage diets before entering the feedlot need to be preconditioned to feedlot conditions (Chapter 11). There are several aspects to preconditioning, including 1) vaccination for diseases likely to be encountered in feedlots, 2) exposure to people and handling and 3) exposure to the higher-energy diets they are finished on in the feedlot. Some commercial entities have developed preconditioning programs largely based on vaccination protocols, especially those for bovine respiratory diseases, e.g. Feederguard (Elders Pty Ltd) and MaxiStart feedlot ready program (Landmark Pty Ltd) and others. Nutritional preconditioning usually involves the introduction of increasing daily amounts of a high concentrate-based diet mixed with forage over a period of 2–3 weeks, which allows rumen microorganisms time to adjust to the change in diet (see also Chapter 11). Ideally, cattle will have been yard-weaned to gain familiarity with people and concentrate feeds.

Electronic marketing

Electronic marketing of livestock is now available for the Australian cattle industry. Producers can follow market trends on a daily basis and can access market opportunities on-line. Various industry-linked and privately run agencies are available to producers and buyers for a small fee for use (e.g. AuctionsPlus). The advantages for producers include access to a wider range of market opportunities, the ability to find markets that specifically fit the stock they are trying to sell (or buy) at a particular time, and reduction in costs associated with other forms of selling. The advantages for buyers include the opportunity to reduce pre-slaughter stress on cattle by transporting directly from the farm to farm or to the abattoir, electronic viewing of stock on the farm before purchase, and a wider scope for selection of animals to suit a particular purpose. A disadvantage of buying livestock this way is that cattle with behavioural problems can be bought, and the problems are not evident until they arrive on the farm of the purchaser. Electronic marketing of carcasses and meat cuts in the meat industry is common, and it is expected that this method will increasingly be used for live animal buying and selling. A variety of portable equipment loaded with sophisticated software is available to support livestock buyers and sellers to implement real-time electronic marketing.

Beef markets

Some 65% of Australian beef meat volume is exported (Thompson *et al.* 2012). The rank order of importance of individual export markets is stable although the variety of specific meat cuts going to each of our major export markets is quite different from one market to another (Fig. 3.3; Thompson *et al.* 2012).

The flow of beef to Australian domestic markets (in 2006) is summarised in Fig. 3.4. The markets that are surprising to many are foodservice, which is almost as substantial as the two major supermarkets combined, and retail butchers, which have contracted as a market since the 1950s but are still significant. Increasingly, butchers are accessing product direct from farmers or groups of farmers as a means of differentiating themselves from supermarkets.

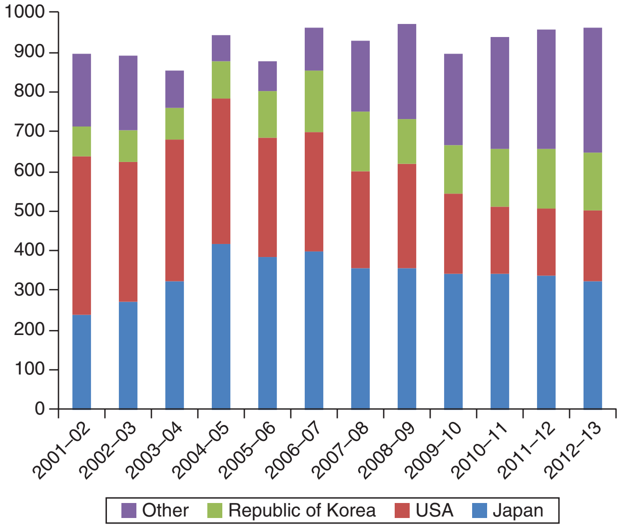


Figure 3.3: Australian beef and veal exports (kilotonnes). Source: Thompson *et al.* (2012, p. 2).

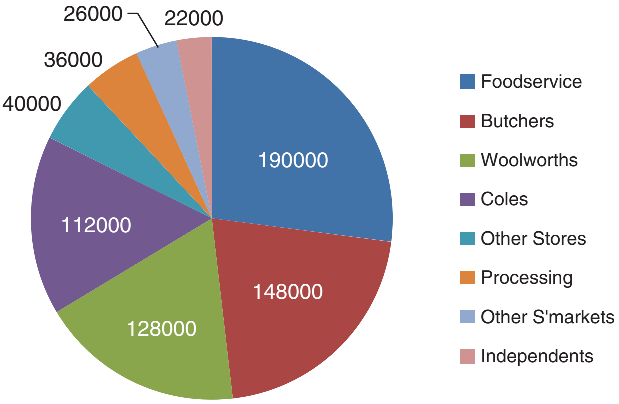


Figure 3.4: Australian domestic beef consumption by various outlets (tonnes). Source: Beef Chain Consortium 2010, p. 71).

'Foodservice' includes substantial catering operations, hospitals, restaurants, prisons and other institutions with a need to feed substantial numbers of clients. 'Independents' here refers to independent supermarkets; 'other supermarkets' refers to small chains.

The role of agricultural value chains

Agricultural businesses in Australia are fundamentally different from most other businesses. For example, there are some 35 000 beef-producing farms. Many are in direct competition with thousands of others. Many are small in output terms. None have a substantial share of total national output. All face the effects of climate variability and resultant beef quality fluctuations. Few have a brand; they are anonymous to the final consumer. Different cuts from the cattle they sell commonly are finally sold in different markets. Most beef producers are price-takers: they cannot dictate the price at which their output will be sold. The exceptions are a few producers who have successfully targeted final consumers who are much more sensitive to beef quality than to price.

Producers therefore have very little control over profit margin sale-by-sale: applying production capabilities to the production of the most attractive output is critical to long-run financial performance.

These characteristics are challenging for producers. They also create problems that other businesses do not face, for linking production capabilities to consumer preferences. The complex array of producers with different production capabilities, coupled with an even more complex array of millions of consumers with diverse preferences in multiple countries, means that key information does not flow easily from one to the other. Compounding this is a trend to consumers increasingly seeking product attributes that are hidden, e.g. eating quality (taste, tenderness), health (fattiness, production regimes), animal welfare (production, slaughter), breed and origin (King Island, Coorong).

The question this situation begs is 'how do producers discover consumer preferences and how do they advise consumers of the attributes of their product?'

For most products this is easily dealt with because products are branded: both producers and consumers are working in product space that is occupied by brands with known, and reliable, attributes. This is not typically the case with beef or most other agricultural products.

While all products have a value chain, most are less critical to the successful operation of markets as mechanisms that align consumer preferences and chain output than agricultural value chains. To make farm output align with consumer preferences, and thereby maximise sales volumes and profit, these chains have to fill the information gaps left by the typical absence of brands on fresh agricultural output.

Historically, this has led to the development of 'house' grading schemes by major processing firms in the beef chain, both for domestic and export markets, and, through contracts with beef producers, by major domestic retailers. More recently, the beef chain has matured through the introduction of a grading system, Meat Standards Australia (MSA), with a trace-back capability. Grading schemes provide a basis for prices paid for product to signal how much market segments value different attributes covered by the scheme.

Recognition of the composition of the beef value chain, and the sheepmeat value chain, has enabled the targeting of quality assurance (QA), on the output side, by AUS-MEAT Ltd (a non-profit company co-owned by Meat and Livestock Australia (MLA) and the Australian Meat Processor Corporation), and market research and promotion, on the consumer side, by MLA. While it is possible for a producer to bypass most of the chain and link directly to customers by contracting with supermarkets or targeting farmers' markets, the reliable and comprehensive creation of relevant information exchange between producer and consumer relies on the QA and marketing mechanisms MLA is sponsoring into the value chain.

With this stronger information flow it becomes possible to better align chain output (and farm output) with customer preferences and to better integrate activities within the chain. This is important in absolute terms because greater profitability per sale is available from improved efficiency. It is also important because the beef value chain is competing with other value chains domestically (sheepmeat, chicken, pork, seafood) and other beef value chains in export markets.

The main strategic options for beef producers

A basic choice all businesses face is whether to produce products with broad appeal and low price ('cost leadership') or to produce products targeted deliberately at one or several market segments, each with a specific set of preferences ('differentiation'). This choice is basic because it is widely believed that it is not possible to adopt both approaches simultaneously: identifying and responding to segment preferences is costly, meaning price will be higher than otherwise. It is not simple to switch from one strategy to the other (Porter 1985). As it is entire value chains that create the final form, price and location of products offered to consumers, this strategic choice also relates to the chain.

In the beef industry these approaches have been described as 'fair deal' and 'convenience', respectively (Beef Chain Consortium 2010). These strategies have only recently emerged in their current form as a result of the increased information flow, integration and QA within the beef value chain and have better aligned the value chain with customer preferences. With this greater attention to customer preferences, consumers have been able to reveal their preferences by responding in their purchasing to the increasingly wider variety of beef product. Whichever strategy a beef producer or value chain is pursuing, product quality is now higher as a result of the improvements in information flows and QA in Australian beef value chains.

Until relatively recently there was no quality-based differentiation across meat cuts in Australian supermarkets. Now there are various brands, more pre-prepared cuts and a greater number of different grades within a single cut. This expansion of beef meat offers to domestic consumers will continue. As it does, the value chain will continue to evolve into a more efficient, customer-driven chain. Those seeking either a fair deal or convenience (differentiated product) will continue to be better served.

With the boosting of QA and customer focus, the roles of beef chain members can change. This occurs as the most logical or efficient provider of desired meat attributes changes. For example, the spread of the adoption of public grading schemes such as MSA reduces the extent to which value chain members, such as specialist retail butchers, can present themselves as the most reliable guarantor of meat quality consistency to the consumer. Likewise, as concern for animal welfare increases among consumers, individual beef producers may have a role in conveying (highly credible) information about on-farm practices to concerned consumers who require validation of production methods.

The strategic choice each beef producer faces is determined by the control they have over the characteristics of their output, especially quantity and quality, and the entry points to the value chain available to them. Farm financial performance in beef production will increasingly depend on finding the best alignment, the best match, between their output and the preferences of buyers they can target.

There is extensive detailed analysis in the Beef Chain Consortium report (2010) of the two main strategic choices facing beef producers. Particularly relevant here is the exploration of the detail of different interrelationships within the beef value chain depending on which strategy is chosen. In basic terms, the distinction is in what economists call ‘vertical integration’: the extent to which one entity in the beef chain exerts control over others. A characteristic that signals the degree of vertical integration is the continuity of trade between parties in the chain.

The fair deal strategy for beef producers involves more limited vertical integration (between the farm and the rest of the chain) than does the convenience strategy. The reason is that, even though there may be considerable vertical integration being undertaken, backwards or forwards, by other chain actors, the fair deal chain strategy is less reliant on tight, or exotic, output specifications being met by beef producers. Beef producers meet largely quantified specifications that go to conversion efficiency and fair average quality (FAQ) eating quality. They do not seek to get engaged themselves in value chain activity beyond the farm and gladly shed ownership of the animals they send off-farm.

Convenience-oriented value chains rely on broader, tighter output specifications, some of which may be qualitative (e.g. organic production, regional source, top MSA grades only). The role of the producer is greater in contributing attributes to the final meat product: other entities in the chain cannot add these attributes if they are absent in the original animal. There is thus greater vertical integration. Ad hoc approaches to procuring beef at auction are too risky and more contracting and long-term relationships with beef producers emerge.

The entity most responsible for integration varies. A major supermarket will use contracts extensively, even solely, to fine-tune integration throughout the value chain, making them the integrator (backwards) in their chain. A farmer targeting highly quality-concerned niches may integrate forward to some degree. This may be MSA-grade plus source-based, such as Ebor Beef in New South Wales (see www.eborebeef.com.au), contract-slaughtered and labelled and distributed through existing specialist butchers, online and restaurants. Or, like Coorong Angus Beef in South Australia (see www.coorongangusbeef.com.au), also distributed through restaurants and online but limiting retail sales to a chain of specialist butcher outlets (Feast!) that it owns and that also retails other brands. This business has effectively assumed full control of the entire value chain for its own Angus beef: this is total vertical integration. (Note: ‘integration’ means control, not necessarily ownership.)

The skill requirements of any integrating entity in the chain are obviously greater the more the functions to be controlled. This is one reason, along with the size of accessible niches, that substantial vertical integration forwards by beef producers is most unlikely to rival the volume of beef handled by chains commanded by very large producers, wholesalers or retailers. It is likely, too, that improved QA and information flow (e.g. MSA grades: see Chapter 2) will lift fair deal segment meat quality to levels that will ensure that this segment continues to dominate the market: consumers will not need to pay premiums to ensure the adequacy and reliability of eating quality. This will continue to limit prospects for beef producer control of beef value chains except in niche markets and larger, but limited, segments seeking branded beef in mainstream outlets such as supermarkets.

TARGETING A MARKET

The majority of cow-calf or breeding operations in Australia, the USA and other countries are small enterprises with fewer than 100 head of cattle (USDA 2011; ABARE 2010; Chapter 4). However, while these small enterprises comprise 92% of US producers (USDA 2011) and 30% of Australian producers (ABARE 2010), they hold only 49% of the US inventory and 3% of the Australian inventory of cows. It has been estimated (ABARE 2010) that a sustainable financially viable commercial enterprise for a family requires around 800 breeding cows in Australia.

Consequently, the focus in this chapter is on planning in larger beef cattle enterprises. Enterprises can be categorised broadly by market as direct for slaughter, feedlot, live export, store cattle or breeders (ABARE 2010). Sub-categories within these market areas target more specialised markets, e.g. long-fed, highly marbled cattle, and enterprise options, including a breeding or a trading focus.

To a large degree, a highly flexible strategic marketing plan is not a realistic proposition, as factors such as long-term ownership, family constraints or interests, climate, proximity to abattoirs, saleyards or transport terminals, and human population densities influence the options available to a producer. Nonetheless, it may be feasible to move to a different property to target more lucrative markets. A dynamic decision-making process that embraces some of the key considerations, such as the type of animals sourced, environmental, pastoral, and genetic factors, is important when producing for target markets. Managers can rapidly access information on production characteristics of most cattle breeds, using genetic evaluation systems such as BREEDPLAN (Barwick and Fuchs 1992) to assist prediction of cattle growth and development (Chapter 17), and use a range of prediction modelling tools to assist on-farm value-adding decisions. Local, national and international market reports are accessible electronically around the clock to support marketing decisions (MLA 2013b).

MARKET SPECIFICATIONS

Several attributes recorded and explicitly sought for live animals and carcasses are collectively referred to as market specifications. These specifications vary with consumer demand, market type and destination. For instance, many market opportunities exist and production could target domestic or export markets; niche marketing could include organic product; and some growers produce animals to specification for feedlot finishing. The preferences of each market segment at the final consumer level are translated, through the value chain, into specifications at each market level, including the beef producer's farm-gate level. Specifications at farm-gate level may refer to characteristics that help determine attributes such as eating quality or to characteristics that determine the presence of an attribute, such as breed or an organic production regime. That is, some characteristics are managed each production cycle while others, such as breed and production regime, are the result of longer-term decisions.

Specification descriptors commonly used for marketing beef cattle include liveweight, sex, age of animals, muscle score and fat depth at several carcass sites. For beef sold over-the-hook, attributes such as muscle pH, marbling score, meat colour, fat colour, fat depth at the P8 site (Chapter 2) and, occasionally, cattle breed, are added to the information used by various segments of the value chain to deliver product that meets market specifications and expectations. Systematic measurement and recording of these attributes is carried out at all export-accredited and most domestic abattoirs in Australia, and this information is used to describe product using either AUS-MEAT or MSA grading systems (Chapter 2).

Other factors such as use of hormonal growth promotants also determine market destination, with some markets, including the European Union, precluding their use. Producers need to match breeding and management strategies to ensure that a high percentage of cattle meet the specifications being targeted. Significant price penalties are incurred when producers fail to meet specifications, and failure to meet ideal weight and fat-depth guidelines is the most common cause of discounts for producers (Andrews and Littler 2007). Specifications for live animals being on-sold will change according to purpose, and producers need to tailor their production outcomes to suit the purchaser. Specific markets can include categories such as store weaners, veal, yearling beef, young beef, short and long day feeder heifers and steers, heavy grass-fed steers (Ox beef), bull beef, and dairy beef. Descriptors for these categories are framed using dentition, liveweight or hot standard carcass weight (HSCW), fat cover and various other market specific descriptors (Table 3.1). Value of animals will be determined using a price grid combining these factors.

APPRAISING SUITABILITY FOR MARKET

Monitoring performance

Suitability for particular markets has traditionally been assessed in a range of ways (Table 3.2), and new and emerging technologies will further assist cattle producers to accurately target and meet short- and longer-term marketing objectives.

Innovations such as ear tag recognition weighing systems installed in the paddock, where cattle are automatically weighed frequently at feeding and drinking points, can greatly assist producers to know how many cattle in a herd meet market weight specifications at a

Table 3.1: Some common categories of cattle and their descriptors

Market category	Dentition	HSCW range	Fat cover	Other descriptors
Store cattle (adult)	• may vary	• may vary	• usually BCS ≤2	• will vary depending on buyer requirements. e.g. pregnant females, cow and calf units, dry females, yearling steers and heifers etc.
Store weaners	• milk teeth	• may vary, though heaviest calves are generally the most profitable	• not usually an important selection factor	• generally sold on a liveweight basis; no sex or breed restrictions
Veal	• milk teeth	• slaughtered before reaching 150 kg	• no minimum fat requirement	• no sex or breed restrictions
Yearling beef	• 0 permanent incisor teeth(up to 18months old)	• 160–250 kg • suited to local butchers • precocious animals meet feedlot specifications • as a guide: export feeder steers 200–270 kg HSCW • domestic feeder weights 160–210 kg steer or heifer HSCW	• local butchers prefer 5–8 mm fat at P8 site and BCS of 2+ • MSA require minimum 3 mm subcutaneous rib fat at quartering site	• steers or heifers • can be grass- or grain-finished
Young beef	• 0–2 permanent incisor teeth(up to 30 months old)	• 160–340 kg • suited to local butchers and supermarkets • supermarkets targeting 220–280 kg HSCW, average 250 kg • export plants top price in 300–340 kg range • average MSA carcass weight is around 280 kg	• local butchers require 5–8 mm fat at P8 site • supermarkets require 8–16 mm fat at P8 site • BCS 2+	• steers or heifers • can be grass (5 mm minimum fat) or grain (7 mm minimum fat) finished • grain-finished animals on feed for 60–70 days
Young beef (prime)	• 0–4 permanent incisor teeth(up to 36 months)	• 220–420 kg • suited to high-end hotels, supermarket trade, restaurants and light export • top price depends on market • MSA 180–340 kg, Jap Ox 240–420 kg	• supermarkets prefer 10–12 mm fat cover and some marbling • restaurants prefer 10–15 mm fat cover and obvious marbling • P8 15–22 mm subject to product trim of excess subcutaneous fat • BCS 3–4	• steers or heifers • can be grass- or grain-finished • restaurant and light export targets likely only met with grain finish of at least 100 days on feed • 2 million hd/yr are grain-fed out of 8 million national slaughter. Most of these are short fed (GFYG 0–2 teeth)

Table 3.1: (*Continued*)

Market category	Dentition	HSCW range	Fat cover	Other descriptors
Prime beef	• 6 permanent incisor teeth(up to 42 months old)	• 240–480 kg • Suited to high-end restaurants, and export	• restaurant and export trade 12–18 mm fat at P8 site • BCS 4–5	• prime steer and ox (female)
Ox (male any age) and cow (over 42 months)	• ox 6–8 permanent incisor teeth • cow 8 permanent incisor teeth	• 240–480 kg • high-quality heavy export trade	• fat 7–22 mm at P8 site • BCS usually 4–5 but depends on target market	• usually grain-finished 100–200 days, and occasionally longer
EU export	• 0–4 permanent incisor teeth, or • 0–2 permanent incisor teeth for high-quality beef quota and Hilton quota	• 240–420 kg • upper limit of 340 kg for Hilton quota	• 6–22 mm at P8 site	• steers or heifers • grass- or grain-finished • no HGP
Japan export	• ox 0–8 permanent incisor teeth • heifer 0–7 permanent incisor teeth(up to 42 months)	• 270–420 kg • high-quality prime beef export trade	• 12–18 mm fat at P8 site • BCS 4–5 • Marbling score ≥AusMeat 3 preferred	• steers or heifers • export targets likely only met with grain finish
Korea export	• 0–4 permanent incisor teeth(up to 36 months)	• 220–280 kg • high-quality light export trade	• 10–15 mm fat cover (BCS 3–4) and obvious marbling • marbling score ≥AusMeat 2 preferred	• steers or heifers • can be grass or grain finished • light export targets likely only met with grain finish
Live export	• varies according to market weight requirements	• liveweight varies according to market, e.g. Indonesia requires cattle <350 kg liveweight	• varies according to destination • usually store condition	• steers or cows, grass-fed • often *Bos indicus* cattle or crossbreeds • can also comprise cull dairy cows • dehorned
Dairy beef	• veal – milk teeth • light weight bulls and cows • heavy bulls, cows and steers fit into several other categories above	• veal 100–150 kg liveweight • light-weight regarded as up to 400 kg liveweight • bulls 600 kg+cows 520 kg+steers 600 kg+	• veal-no minimum fat requirement • 5 to15 mm fat cover • 15–25 mm fat coverBCS 3–5	• no dairy breed restrictions • male or female • grass- or grain-finished • crossbred with early-maturing high marbling breedsgives market flexibility • discounted on muscle score and fat cover generally

GFYG = Grain-fed yearling, HGP = hormone growth promotant, HSCW = hot standard carcass weight, BCS = body condition score, MSA = Meat Standards Australia.

given time (Chapter 18). It is likely that remote monitoring systems for cattle will increase in use and sophistication, particularly in more extensive production systems.

Body condition score as an aid to market selection

Body condition scoring (BCS) is an established, non-invasive technique in beef cattle, and is an important assessment of the live animal for suitability to meet prescribed market specifications (Gaden *et al.* 2005). BCS is usually based on a 5 point grading scale (1–5) of descriptors. These descriptors range from grade 1 = very poor condition (emaciated), Grade 2 = poor condition (lean), Grade 3 = moderate condition, Grade 4 = good condition and Grade 5 = very good condition (fat). A BCS estimate is a subjective measure used to determine the condition or fat cover of an animal relative to its body size (Evans 1978). The assessment is based on the assumption that the score given is related to reserves of body fat in the animal in a predictive way (Finger *et al.* 1981). The technique involves palpation of the live animal if possible, to determine the thickness of the fat cover at various body depots such as the rump, loin, brisket and perineum. Visual assessment can also be used to determine fatness, and is routinely used at points of sale of cattle, such as commercial cattle yards. Reference points for visual assessment include the P8 rump site, the hip, loin, shoulder and brisket. Estimation of BCS and fatness in live animals is only as reliable as the trained assessor conducting the scoring. Training in BCS assessment sometimes combines visual assessment and manual palpation with other techniques such as ultrasonography and digital imagery to improve accuracy. BCS is an accurate predictor of reproductive capability in breeding herds (Chapter 14). The use of strategic feeding in conjunction with routine evaluation of BCS promotes efficient use of pasture and supplements and should lead to higher profitability, with more slaughter animals grown to specification.

Accurate assessment of BCS and fatness in the live animal as an indicator of carcass fat depots is an important skill which cattle producers should possess. Market specifications are usually very specific, and most usually allow only a small range in fat depth (mm) at various carcass depots. McKiernan and Sundstrom (2006) assert that buyers and abattoirs will heavily discount the price offered for animals failing to meet specific carcass fat specifications, above and below the range. Too much fat is wasteful, reduces saleable meat yield and can mask muscle definition, thereby making live animal assessment of the carcass cutability more difficult. Too little fat can cause carcasses to chill too quickly and dry out in the chillers (McKiernan and Sundstrom 2006) and lower eating quality (Chapter 2).

Fat coverage can also be influenced by cattle breed, with *Bos indicus* breeds usually leaner than *Bos taurus* breeds in most body depots. Crossbreeding strategies that utilise breed differences and hybrid vigour (Chapter 17) to enhance growth performance, musculature and fat

Table 3.2: Monitoring tools for assessing performance in the field

Category	Traditional method	Current method	Emerging methods
Weight gain	Visual appraisal	Weigh animals at yarding	Remote weighing of sentinel animals
Market suitability	Judgement of producer based on prior experience, and subjective feedback from wholesalers	Objective inspection of animals at the abattoir pre-slaughter, data recording, and feedback to cattle producers	MSA grading data that appraises a range of parameters so that individual carcasses meet current market specifications
Fatness and muscle score	BCS assessment by visual appraisal in the paddock or manual palpation in a cattle crush	Grading of carcasses at slaughter, and measurement of fat depth at various depots across the carcass using a P8 cut-and-measure knife. Muscle score also assessed at slaughter	Pre-slaughter fat depth and muscle score measurement using ultrasound imaging, and high throughput MRI scanning for muscle mass
Health	Visual appraisal at point of sale, using behavioural and physical observations	Ante mortem inspection at the abattoir, post mortem carcass inspection, and individual animal feedback to producer	Rapid tissue examination techniques for chemical residues, microbial contamination and heavy metal storage

partitioning are common. Producers can maximise returns by meeting target specifications more often, and using crossbreeding to meet market opportunities that progeny would otherwise fail to meet.

SPECIALISED PRODUCTION SYSTEMS AND NICHE MARKETS

Niche markets, which are small segments, often create the opportunity for the beef producer to increase their role in the value chain because the attributes the customer seeks can only be provided by the producer. The greater the proportion of attributes provided by the farmer, the greater they can expect their output price to be. This does not mean price will be under greater control but that it will be a higher average *in the appropriate niche*. The first example discussed here is organic product, which cannot exist as an attribute unless the farmer creates it. The challenges to meeting the specifications for this niche, and to coping with other value chain functions (such as assembling sufficient product for continuity of supply), have to be met for the higher average prices available to translate into higher average profitability for the beef producer.

The most assured profit improvements in beef production are those that are achieved in on-farm production systems. These are not troubled by the vagaries of markets and output prices. They therefore occupy a similar strategic role, as a potential contributor to profit, as niche-seeking strategies. Both hold the possibility of productivity increase: one by increasing the value to the value chain of farm output; the other by driving down production costs.

Organic and biodynamic beef production

The number of farmers engaged in certified organic and biodynamic beef production is growing steadily in some parts of the world, particularly in the USA (OTA 2011) and many European countries, although this trend remains comparatively subdued in Australia (Mitchell *et al.* 2010; Wynen *et al.* 2011). Although organic livestock production has been established for many years in several European countries, the total market for beef was 1.6% in 2003 (Vaarst *et al.* 2006). Product certified as organic usually commands a premium price (McCoy 2002), although costs incurred to maintain certification, lower production and productivity (Wynen 2006), and costs associated with product delivery to primarily boutique market outlets, must be factored in to this. Although a market niche exists for certified organic product, there is a lack of evidence to support contentions of nutritional benefits from ingestion of organic foods in general (Dangour *et al.* 2010) or beef specifically. Concerns have also been raised about whether health and welfare standards can consistently be met in organic beef production systems in Europe (Nielsen and Thamsborg 2005), and similar concerns apply to pasture-based production systems in Australia. To the best of our knowledge there is no scientific basis for biodynamic production methods.

Certified organic beef can be produced and marketed after accreditation standards have been met for three consecutive years, and farms certified as organic can legally label product as organic after being accredited (McCoy 2002). Biodynamic farming is a form of organic farming that embraces a farming systems approach which emphasises the soil–plant–animal complex. Biodynamic farms utilise manures and composts free of synthetic chemicals to maintain their accreditation as a producer of organic food. Properties certified as organic adhere rigidly to the National Standards for Organic and Biodynamic Produce administered by the Australian Quarantine Inspection Service (AQIS).

Careful enterprise planning is required for conversion to organic and biodynamic farming, with the long accreditation process and long intergenerational interval for cattle breeding not linked to market trends. The decision to change to organic farming is a long-term, strategic decision that requires a full understanding of, and total commitment to, the principles involved. Farmers interested in converting to organic production often commit only a portion of their enterprise in the first instance, to build experience. Organic farms often comprise more than a single enterprise, for protection against failure of a particular product in the market place, and this approach is particularly important when starting a beef enterprise. For ease of compliance, most producers of organic beef try to operate closed herds to ensure that animals that don't meet compliance standards are not accidentally introduced to their farm, which would threaten hard-won accreditation status. Formation of regional strategic alliances with other organic farmers can strengthen consistency of supply and marketing opportunities (McCoy 2002; Robinson and Cox 2006) for brand development, promotional campaigns, restocking and breed development.

Export opportunities for Australian organic beef are largely focused on Japan, with some European countries also importing organic beef from Australia, the USA and Argentina (McCoy 2002). Domestic consumption in Australia is minor even though major supermarket chains such as Coles and Woolworths devote shelf space to organic produce, including meat (McCoy 2002). Advertising campaigns for beef sometimes use 'chemical free' and 'no added hormones' slogans to differentiate supermarkets and to allay any consumer concerns about the use of hormone growth promotants. HGPs are legal products in Australia and have been assessed as safe for cattle and consumers by a large number of regulatory authorities. However, beef exported into EU countries has to be certified that HGPs were not used in the production of those cattle. Frequent meat analysis and animal traceback recording ensures that this standard is met.

Australia exports the second-largest volume of beef worldwide, and all areas of the supply chain are geared to volume production and handling (Chapter 4). For this reason alone, Australian producers of organically grown beef are likely to remain on the fringe of the beef industry as suppliers to boutique markets and speciality food outlets. The potential to establish regional niche markets for organic beef in Australia has been explored (Robinson and Cox 2006), with the conclusion that opportunities exist. To retain compliance for organic accreditation, all areas of the supply chain must meet hazards analysis critical control points (HACCP) guidelines for organic food storage, handling, processing, packaging and transport. Cattle must be slaughtered in organic certified approved abattoirs.

Dairy beef

In Europe, the USA and New Zealand dairy beef contributes a substantial percentage of finished beef production. In the USA, the estimated 8–8.5% contribution to finished steers suggests that Holstein genetics may be the largest recognisable single-breed source of beef (Schaefer 2005). Holstein steers represent 15–20% of lot-fed steers in the USA (Rust and Abney 2005). In New Zealand, dairy breeds dominate beef production, providing approximately 50% of the weight of beef produced and slightly less than 50% of the value of beef produced (Charteris *et al*. 1998). In Australia, the contribution of dairy breeds is less, reflecting the dominant and specialised contribution of northern beef production. While culled dairy cows contribute substantially to beef produced in many countries, including Australia, their role is not considered here. Bull calves produced from dairy cows provide veal, and in many countries this is the predominant market for male calves of dairy origin. There is an established dairy beef industry in Australia that has largely grown opportunistically by utilising male calves which are reared and grown to supply specialised beef markets, rather than being slaughtered as 'bobby calves' (MLA 2007). Crossbred dairy females rear excellent calves because of their high milk yield, and rapid growth of dairy beef calves is an essential requirement for profitability. Sire selection in a dairy beef enterprise is based on market opportunities for on-selling calves for rearing on pasture, or feedlot finishing.

Traditionally, many dairy breeds were developed to be dual-purpose. Such breeds include Brown Swiss, Simmental, Dairy Shorthorn and Holsteins; breeds such as Jersey, Ayrshire and Guernsey tend to be more specifically dairy breeds. The Holstein breed, which dominates modern dairy production, can be considered a special case European breed beef animal. Compared with British breed cattle such as Angus and Herefords, the Holstein steer provides a leaner carcass at a similar weight and an ~5% lower dressing percentage. However, the yield of primal cuts derived from Holsteins appears to be comparable to beef breeds. Schaefer (2005) reviewed the yield and quality of Holstein beef and concluded that the 'quality of Holstein beef, in terms of palatability characteristics, is not different from beef derived from beef breed steers of comparable age and gross composition'. Rust and Abney (2005) provided a review of comparisons between Holstein and beef steers, including detail of carcass and meat quality differences.

Purebred dairy cattle, especially Holsteins, provide one source of dairy beef, however, dairy crossbred cattle are also a substantial source of beef. Beef bulls are mated to dairy cattle in seasonal calving herds to allow a clear differentiation between calves bred by artificial insemination and those from natural breeding, to produce calves of smaller birth weight (e.g. Angus, Wagyu), especially from dairy heifers, and for special-purpose cross breds. In the latter case, many beef breeds have been used; notable examples include Belgium Blue cattle used for increased growth rates, muscling and stature and Wagyu cattle for increased marbling and stature of the resulting crossbreds.

Rust and Abney (2005) collated data from studies that compared the performance of Holstein steers to those of other beef breeds including Hereford, Angus and Simmental. Weighted average differences over the 13 studies were not significantly different for initial weights, final weights, average daily gain, dry matter intake, feed to gain or percentage of dry matter intake (DMI) as a percentage of bodyweight. Differences between the performances, however, were of sufficient scale to suggest merit in further evaluation, as there was an 8.2% lower initial weight, a 5.8% higher final weight, a 2.6% higher average daily gain, a 4.7% higher DMI, 6.7% higher feed to gain and 2.3% higher percentage of DMI as a percentage of bodyweight for Holsteins *v.* the beef breeds. Compared with the beef breeds, Holsteins had significantly less backfat thickness (39%), rib eye area (90%) and yield grades, but were very similar to beef breeds in marbling and kidney, pelvic and heart fat. Further, Rust and Abney (2005) presented commercial feedlot data suggesting better grading performances and lower DMI differences for Holsteins *v.* beef breeds raised under these conditions. Notable among the findings for the Holstein grading difference is a propensity to marble compared with beef breeds. However, marbling and carcass quality were lower for Holstein bulls than for steers of other breeds. In observational studies, Purchas and Zou (2008) and Mills *et al.* (1992) concluded that differences in fat quality between Holstein and crossbred steers would be of little nutritional significance to people who eat meat. The potential to marble and contribute to production of a larger-frame animal capable of finishing at a younger age has led to the use of Wagyu sires over Holstein cattle to produce high-quality beef.

The significance of dairy-derived beef may diminish as use of sexed semen increases in the dairy industry, to produce more female replacements. However, the same technology may be used to more carefully target production of beef crossbred steers in certain circumstances. Notwithstanding these opportunities, it is likely that the dairy industry will continue to provide high-quality table beef and manufacturing beef into the future.

Bull beef

Bull beef is a specialist market and has, at times, been a substantial market for Holstein calves from dairy sources. Typically, dairy bull calves are purchased at ~12 weeks of age and slaughtered some 15 months later at around 400–420 kg and carcass weights of 240–270 kg. In some areas of New Zealand, the bulls are maintained to a later age and higher weight before slaughter. These cattle can pose management challenges because of the development of male characteristics that can result in fighting, injuries to cattle and producers, and damage to fences and facilities. In New Zealand, up to 20% of beef production comes from bulls (Doyle *et al.* 1989), reflecting a premium paid for Holstein bull carcasses compared with steer carcasses. Cosgrove *et al.* (2003) reviewed a series of farm trials conducted in New Zealand over 16 years and found very consistent annual liveweight gain per unit area and a dressing % (defined as carcass weight as a proportion of fasted liveweight) that ranged from 46% to 50% for bulls killed at 350–420 kg LW and 16–19 months of age. There is less emphasis on bull beef production in Australia than in some other countries, though it remains a market outlet for dairy and beef bulls that are surplus to requirement, and culled animals.

The advantages of bull beef production systems are greater weight gains, and greater average daily efficiency of weight gain compared to steers. The data from Preston and Willis (1975) were analysed to provide unweighted means to evaluate trials. These studies showed an increase (± standard error) in average daily gain (n = 14 trials) of 0.11 ± 0.01 kg per day and a better feed conversion efficiency (FCE) of 0.52 ± 0.07 kg per kg of gain (n = 12 trials) than steers. Differences in FCE between bulls and steers were significantly greater for studies conducted with a lower starting weight, suggesting that the differences in efficiency reflect differences in body composition, with bulls being leaner than steers. This difference is also reflected in a 15% higher maintenance component for bulls than for steers of equal weight. Therefore, bulls are not well suited to low-growth production systems.

Disadvantages include the costs and risks of handling and managing bulls, which can be aggressive and exhibit other dominance behaviours and differences in meat quality. Bulls tend to have darker, leaner beef, especially when older, and less tender beef than castrates (Chapter 2). Electrical stimulation and ageing of beef may negate differences in tenderness between steers and bulls (Hopkinson *et al.* 1985), but this is not always the case.

PREDICTION MODELLING FOR FINISHING CATTLE

Perhaps the most difficult task in achieving greater returns for producers is to effectively identify, secure and successfully target markets. Often, markets are developed over time through demonstration of performance and strong interpersonal relationships. Increasingly, however, these relationships are the result of a drive by producers to achieve better or more reliable markets, or to differentiate stock sold to create a premium for a perceived value to the consumer. Increasingly, there has been interest in value-adding value chains, starting at the producer level, with an orientation towards meeting consumer demands. The challenges in establishing effective value chains are significant in highly volatile, low-margin agricultural markets including beef, and remain high even for

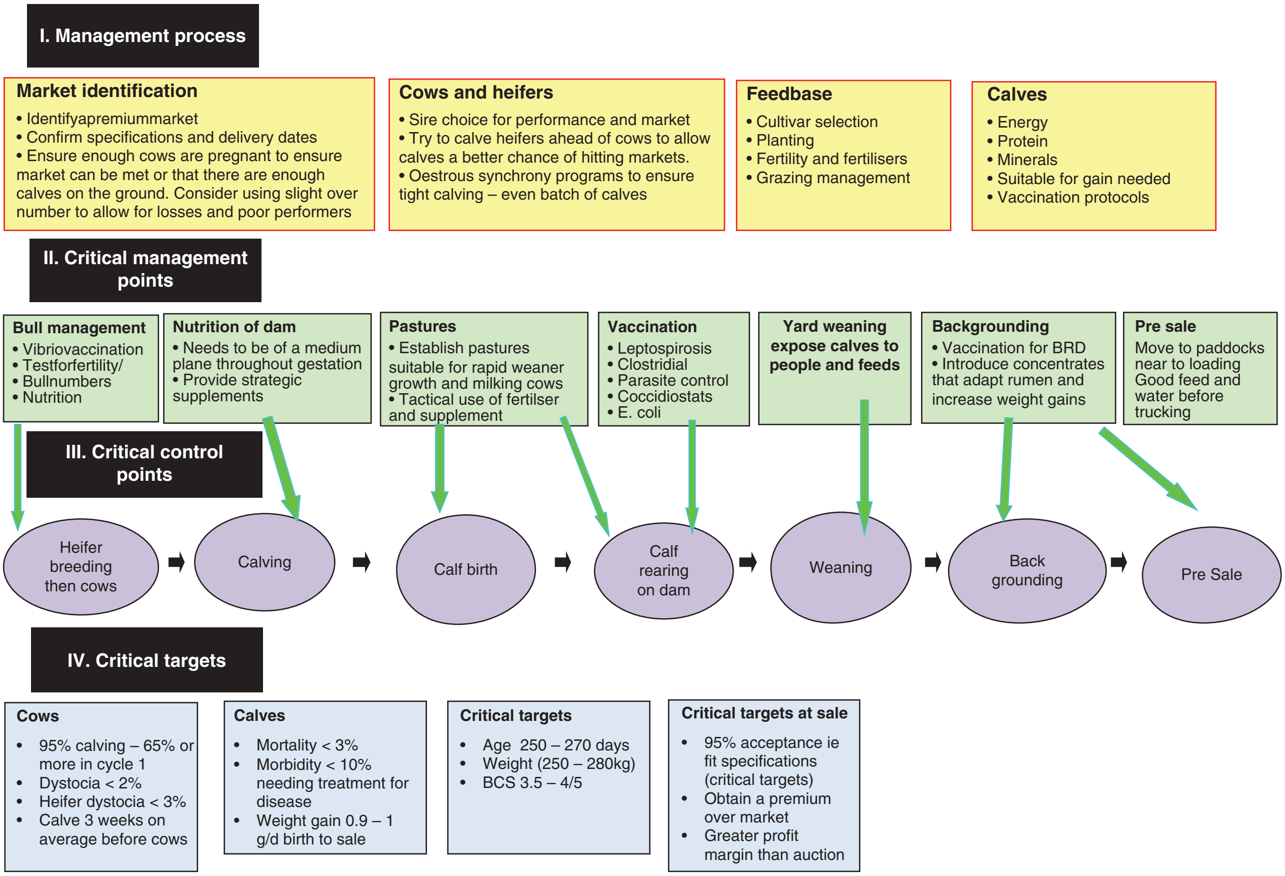


Figure 3.5: HACCP used to target and deliver weaners to a beef feedlot market. In this case, a premium is available for cattle that are likely to perform well in the feedlot. Source: I.J. Lean, SBScibus.

differentiated high-value product, e.g. long fed beef. There is a significant risk of loss if market conditions change: the lag time between identifying a market and producing an animal from breeding to finishing can range from three to five years, and sometimes longer. Therefore, it is extremely prudent to have potential alternative markets identified for unsecured cattle or to 'lock in' pricing as early in a production process as is feasible. The latter can provide benefits for intermediate producers in the supply chain and those involved in point of sale, if premiums can be extracted from the market for product that meets specifications.

The process of achieving targeted aims is best described in terms of a quality control process. In many industries, including the agricultural industries, HACCP methods provide a framework for a more successful and efficient performance. An example of this approach is used here to demonstrate the principles of targeting markets and the way that predictive models can be used to finish cattle, and to highlight some of the tools available to producers and their advisers. HACCP provides a logical framework to understand production as a series of time-related events and actions needed to achieve an outcome (Figs 3.5, 3.6).

Annotations for Figs 3.5 and 3.6

- Seasonal conditions determine that the best calving time is in late winter (Fig. 3.5). Planned start of calving is 21 July.
- Fig. 3.6 provides details of pasture growth and dry matter demand (as an integrated cow–progeny requirement, i.e. DMI for cows and calves).
- Stocking rate is determined by risk – aim: to provide minimal supplementary feeding and achieve targets. Stocking rate is 2 cows per hectare.
- A pasture plan has identified that poor summer growth of the mixed pasture is augmented by the lucerne. The amount of lucerne is insufficient to meet the overall needs. Feed quality and abundance in winter and spring are addressed by strategic use of supplemented oats. These will allow either dry standing feed to accumulate on the mixed pasture, or forage conservation.

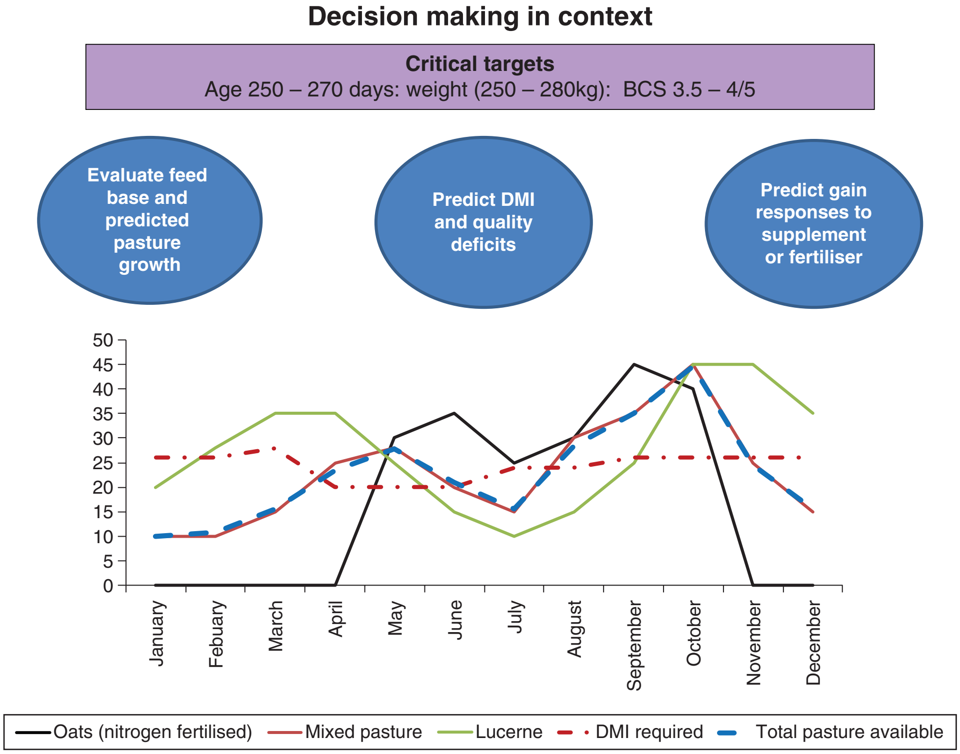


Figure 3.6: Decision-making in context: agronomic and nutritional models to effectively assess the value of intervention strategies. Oats, mixed pasture, lucerne and total pasture available kg/DM per ha, dry matter intake required per ha in northern NSW. Source: I.J. Lean, SBScibus.

- It is recognised that the amount of lucerne planted cannot meet the likely feed requirements for cows and calves across the summer. Both cows and calves need supplement in summer. Growth rates of the calves will not meet needs for achieving targeted weight gain.
- Weaning is strategically targeted to reduce the feed requirement of the cows and to supply lucerne for the calves (December–February target flexible given seasonal conditions).
- Cows will be able to maintain weight up to December, but start to lose weight thereafter. Excessive losses will not be regained before calving on pastures available, because the mixed pasture is not of high energy or protein density. Lucerne will be fed to calves and oats are not available until just before calving. Hence, need to monitor weight and body condition score.
- Risks of yard weaning in summer – rainfall and scours, flies and pink-eye (*Moraxella bovis*).
- Supplement is determined by 1) need to control pasture residuals and achieve regrowth, 2) opportunity to deliver minerals as well as energy and protein, and 3) cost-efficacy of different feed options.

The key points of action are identified and the risks are highlighted. At each point in the process, achievement of intermediate goals (critical targets) is important. For example, a failure to produce sufficient calves may result in a failure to meet specified numbers for a contract, or insufficient preparation in backgrounding may result in a failure to perform in the feedlot and increased risk of failure to renew contracts. A failure to control parasites may result in poor performance, to the extent that the opportunity to catch up and meet weight gain targets becomes prohibitively expensive. By examining the key risks and preventing or controlling them, a producer adds cost to the production system. However, the sensible application of strategies to prevent failure and to meet specified markets that provide a premium will result in greater profit. The process of targeting a market, and examining the inherent costs of doing so, allows budgets to be developed for production. It also allows producers to understand options including the use of cost-efficient methods of increasing gain, including the use of HGPs. For animals that fail to meet target specifications there is usually an alternative market opportunity (Table 3.1), although the premium price might not be achieved.

The major challenges to meeting performance targets in pasture-based cattle production systems are variable seasonal conditions. Timing of calving is critical as calving should, most often, be directed to the pasture growth and quality curve. In northern Australia, which has highly seasonal growth, calving time has a very strong impact on weaner performance. Even with calving targeted and planned well, growth of pasture will be variable, but producers have a large number of options to gain control of pasture systems including use of fertilisers, changing grazing pressures through altering stocking rates and rotations, application of plant hormones, and supplementary feeding with feeds designed to improve performance on the available pasture. Ultimately, there are enough tools to meet particular markets even under adverse environmental and climatic situations. The more critical decisions relate to whether the target market can be met cost-effectively. At this point, the decision to pursue a chosen market or to identify an alternate market needs to be made: enterprise profitability, and occasionally long-term viability, is determined by this decision. Further detail on the approaches used to meet market specifications is provided in Chapters 9 and 10.

Producers can now access many online tools to help them with this decision-making process. For example, Meat and Livestock Australia (MLA 2012) has several tools, including stocking rate calculators, feed demand calculators, a rainfall to pasture growth outlook tool, calving histograms, a health costs calculator and estimated costs of production (<http://www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/>). Most critically, these tools assist producers to better understand the likely responses to additional inputs, especially feed and stocking rates. Other industry models include GrassGro and Grazfeed developed by the CSIRO (Moore *et al*. 1997), the Cornell Net Energy and Protein System (CNCPS 2012) and various feeding standards including texts such as NRC for Beef Cattle (1996). The application of feeding standards and understanding basic nutrition will assist producers to make sound decisions about the use of supplementary feeds and to feed with confidence (Chapter 16). It is worth noting that the available feed standards do not address the interactions of cattle fed with supplements and pastures. This aspect of integrating nutrition with agronomy and risk management requires the use of agronomic and nutritional models to effectively assess the value of intervention strategies. Fig. 3.6 examines the potential impacts of providing supplement to a group of weaners to meet a target market, and provides a method of understanding the critical information required to implement such decisions.

REFERENCES

ABARE (2010) *Australian Commodity Statistics: Meat – Beef and Veal*. Australian Bureau of Agricultural and Resource Economics, Canberra. <http://adl.brs.gov.au/data/warehouse/pe_abares99001762/ACS_2010.pdf>.

Andrews T, Littler B (2007) Market specifications for beef cattle. Primefacts 621. NSW Department of Primary Industries.

Anonymous (2012) <http://farmbiosecurity.com.au/wp-content/uploads/2012/11/National-Cattle-Health-Statement.pdf>.

Barwick S, Fuchs W (1992) Breeding objectives for beef cattle. In *Animal Breeding: The Modern Approach*. pp. 141–154. Post Graduate Foundation in Veterinary Science, University of Sydney.

Beef Chain Consortium (2010) *Strategic Fit and Performance Measurement Issues in the Beef Sector of Australian Agric.-Business: A Study Completed over 24 Months from January 2007 to January 2009*. Logistics Association of Australia Pty Ltd. <www.laa.asn.au/pdf/BeefChainReport.pdf>.

Charteris PL, Garrick DJ, Morris ST (1998) New Zealand beef industry structure and opportunities to improve income. *Proceedings of the New Zealand Society of Animal Production* **58**, 228–230.

CNCPS (2012) *Cornell Net Carbohydrate and Protein System*. Version 6.1. Cornell University. <www.cncps.cornell.edu/downloads.html>.

Cosgrove GP, Clark DA, Lambert MG (2003) High production dairy-beef cattle grazing systems: a review of research in the Manawatu. *Proceedings of the New Zealand Grassland Association* **65**, 21–28.

Cox RJ, Zhou ZY, Jung-Sup C (2003) Beef supply chains in Australia: implications for Korean beef industry. *Journal of Rural Development* **26**, 83–112.

Dangour AD, Lock K, Hayter A, Aikenhead A, Allen E, Uauy R (2010) Nutrition-related health effects of organic foods: a systematic review. *American Journal of Clinical Nutrition* **92**(1), 203–210. doi:10.3945/ajcn.2010.29269.

Doyle CJ, Baars JA, Bywater AC (1989) A simulation model of bull beef production under rotational grazing in the Waikato region of New Zealand. *Agricultural Systems* **31**, 247–278. doi:10.1016/0308-521X(89)90024-3.

Evans DG (1978) The interpretation and analysis of subjective body condition scores. *Animal Production* **26**, 119–125. doi:10.1017/S0003356100039520.

Finger SE, Brisbin IL, Smith MH (1981) Kidney fat as a predictor of body condition in white-tailed deer. *Journal of Wildlife Management* **45**(4), 964–968. doi:10.2307/3808104.

Gaden R, Duddy G, Irwin J (2005) *Identifying Live Animal Condition Scoring Systems for the Australian Livestock Export Industry*. Meat and Livestock Australia, Sydney.

Hopkinson SF, Ringkob TP, Bailey CM (1985) Cutability and the effect of electrical stimulation and aging on tenderness of beef from young intact males and castrates. *Journal of Animal Science* **60**, 675–681.

McCoy S (2002) Organic beef: a production guide. Bulletin 4518. Rural Industries Research and Development Corporation, Canberra.

McKiernan B, Sundstrom B (2006) Visual and manual assessment of fatness in cattle. Primefacts 282. NSW Department of Primary Industries.

Mills EW, Comerford JW, Hollender R, Harpster HW, House B, Henning WR (1992) Meat composition and palatability of Holstein and beef steers as influenced by forage type and protein source. *Journal of Animal Science* **70**, 2446–2451.

Mitchell A, Kristiansen P, Bez N, Monk A (2010) *Australian Organic Market Report 2010*. Biological Farmers of Australia, Chermside.

MLA (2007) *Livestock Production*. Meat and Livestock Australia. <http://www.mla.com.au/Livestock-production>.

MLA (2012) Meat and Livestock Australia. <http://www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/Cost-of-production-beef>.

MLA (2013a) <http://www.mla.com.au/Meat-safety-and-traceability/Livestock-Production-Assurance/Vendor-declarations>.

MLA (2013b) *Marketing Beef and Lamb*. Meat and Livestock Australia. <http://www.mla.com.au/Marketing-beef-and-lamb>.

Moore AD, Donnelly JR, Freer M (1997) GRAZPLAN: decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture sub-models, and the GrassGro DSS. *Agricultural Systems* **55(**4)**,** 535–582. doi:10.1016/S0308-521X(97)00023-1.

Nielsen BK, Thamsborg SM (2005) Welfare, health and product quality in organic beef production: a Danish perspective. *Livestock Production Science* **94**, 41–50. doi:10.1016/j.livprodsci.2004.11.023.

NRC (1996) *Nutritional Requirements of Beef Cattle*. 7th edn. National Research Council. <www.ag.ndsu.edu/pubs/ansci/beef/eb74w.htm>.

Organic Trade Association (2011) *US Organic Industry Overview*. <https:www.ota.com/bookstore/14.html>.

Porter ME (1985) *Competitive Advantage: Creating and Sustaining Superior Performance*. Free Press, New York.

Preston TR, Willis MB (1975) Males. In *Intensive Beef Production*. (Eds TR Preston and MB Willis) pp. 268–288. Pergamon Press, Oxford.

Purchas RW, Zou M (2008) Composition and quality differences between the longissimus and infraspinatus muscles for several groups of pasture-finished cattle. *Meat Science* **80**, 470–479. doi:10.1016/j.meatsci.2008.01.013.

Robinson HJ, Cox RJ (2006) Is there a potential for certified clean and natural beef in northeast Victoria? *AFBM Journal* **3**(1), 39–49.

Rust SR, Abney CS (2005) Comparison of dairy versus beef steers. In *Proceedings Managing and Marketing Quality Holstein Steers*. Department of Animal Sciences, University of Wisconsin. <www.extension.umn.edu/dairy/holsteinsteers/pdfs/papers/>.

Schaefer DM (2005) Yield and quality of Holstein beef. In *Proceedings Managing and Marketing Quality Holstein Steers*. University of Minnesota Dairy Extension, Rochester, MN. <www.extension.umn.edu/dairy/holsteinsteers/pdfs/>.

Thompson T, Martin P, Mifsud C, Foster M (2012) *Commodity Outlook and Financial Performance of Key Agricultural Industries in the Northern Australia Pastoral Zone*. ABARES Conference paper 12.9, June, Canberra.

USDA (2011) *Livestock and Animals*. US Department of Agriculture. <http://www.nass.usda.gov/Statistics_by_Subject/index.php>.

Vaarst M, Weisbjerg MR, Kristensen T, Thamsborg SM, White A, Roderick S, Lockeretz W (2006) Animal health and nutrition in organic farming. In *Organic Agriculture: A Global Perspective*. (Eds P Kristiansen, A Taji and J Reganold) pp. 167–185. CSIRO Publishing, Melbourne.

Wynen E (2006) Economic management in organic agriculture. In *Organic Agriculture: A Global Perspective*. (Eds P Kristiansen, A Taji and J Reganold) pp. 231–244. CSIRO Publishing, Melbourne.

Wynen E, Mitchell A, Kristiansen P (2011) Organic farming in Australia. In *The World of Organic Agriculture: Statistics and Emerging Trends 2011*. (Eds H Willer and L Kilcher) pp. 219–222. IFOAM, Frick, Switzerland.

This page intentionally left blank

4 World beef production

A.E.O. Malau-Aduli and B.W.B. Holman

INTRODUCTION

Beef cattle, like other ruminants, have a complex digestive system inhabited by rumen microorganisms that can effectively convert pastures and other plant-derived products to meat and milk for human consumption (Chapters 15 and 16). To be able to appreciate the diversity in cattle performance in global beef production systems, a firm understanding of beef cattle performance indices and unique climatic, management and production systems around the world is essential. For example, in Australia, specialised beef breeds and crossbred cattle dominate beef production, whereas in New Zealand, Europe and the USA (Chapter 5), dairy beef constitutes a substantial percentage of finished beef production because land is too expensive to run cattle specifically for producing beef. An estimated 8–8.5% contribution of Holstein genetics to finished steers, representing the largest recognisable single-breed source to beef production in the USA, has been reported (USDA 2011; Schaefer 2005). Holstein steers also represent 15–20% of lot-fed steers in the USA (Rust and Abney 2005). In New Zealand, dairy breeds also dominate beef production, providing approximately half the weight of beef produced and slightly less than 50% of the value of beef produced (Charteris *et al*. 1998). In Australia, nearly 75% of the land mass is suitable only for beef production as the soil is too poor and rainfall is too low for cropping and the returns from wool are too small due to the labour-intensive nature of the production system. This chapter gives an overview of global beef production systems, industry characteristics and outlooks for the beef industries in Australia (Chapters 9 and 10), India, Argentina, Brazil (Chapter 6), the USA (Chapter 5), Canada and the European Union, to represent selected regions in Oceania, Asia, South America, North America and Europe. Descriptions of the operational peculiarities and diversity in management practices that integrate genetics, nutrition and other environmental key drivers of profitability are presented.

OVERVIEW OF GLOBAL BEEF PRODUCTION SYSTEMS

Global beef cattle population and annual slaughters have been on a small increase from 2005 to 2010, with Australia, Brazil, the USA, India, Argentina, and the EU as major players. Brazil and India have the largest population of cattle with a consistent growth in numbers, compared to Australia, New Zealand, the USA and the EU with negligible cattle population increases from 2005 to 2010. Argentina, on the other hand, recorded a decrease in numbers. In terms of annual beef cattle slaughters, Brazil and the USA are the dominant countries (Table 4.1).

Australia

Background

Australia accounts for ~4% of global beef production (Fig. 4.1), is the world's second-largest beef exporter after Brazil (Bell *et al.* 2011) and the sixth-largest beef-producing nation (Tozer *et al.* 2010) with a total herd of 28.8 million head of cattle (McRae 2012), representing a 2.2 million increase from 26.7 million in 2010 (Table 4.1, Fig. 4.2). The beef industry employs over 120 000 people and uses ~43% of Australia's total land mass (Burrow 2010; Bell *et al.* 2011).

The Australian beef industry can be broadly categorised into the northern and southern beef production

Table 4.1: World beef cattle population and annual slaughter

Country	2005	2006	2007	2008	2009	2010
			Year			
		World beef cattle population ('000 000 head)				
Argentina	57.03	58.29	58.72	57.58	54.46	48.95
Australia	28.18	28.39	28.04	27.32	27.91	26.73
Brazil	207.16	205.89	199.75	202.31	205.31	209.54
Canada	14.93	14.66	14.16	13.90	13.18	13.01
China	90.13	87.55	82.07	82.82	82.63	83.80
India	192.02	195.54	199.08	202.70	206.40	210.20
New Zealand	9.51	9.61	9.66	9.72	9.96	9.86
USA	95.44	96.70	96.57	96.04	94.52	93.88
EU	91.31	90.62	90.73	90.90	90.22	89.44
World	1368.03	1384.06	1389.85	1410.28	1419.07	1430.10
		Beef cattle slaughtered annually ('000 000 head)				
Argentina	14.25	13.42	14.96	14.66	16.05	11.48
Australia	8.85	8.40	9.08	8.63	8.52	8.31
Brazil	39.43	41.23	42.33	40.44	39.47	39.40
Canada	4.47	4.16	3.82	3.84	3.71	3.75
China	40.66	41.58	40.60	41.46	43.00	44.17
EU	29.52	29.31	29.00	28.88	28.55	28.72
India	9.58	9.76	9.93	10.11	10.30	10.60
New Zealand	3.80	3.70	3.63	3.84	3.88	3.90
USA	33.31	33.85	33.72	35.51	34.47	35.33
World	289.23	295.60	298.64	301.73	304.21	304.25

Source: FAO (2012).

systems (Chapters 9 and 10). The dominant form in the northern production zone, comprising Northern Territory and northern regions of Queensland and Western Australia, are large cattle herds in extensive, low-input, native pasture grazing systems with low stocking rates (many under corporate ownerships), and in feedlots (Chapter 11).

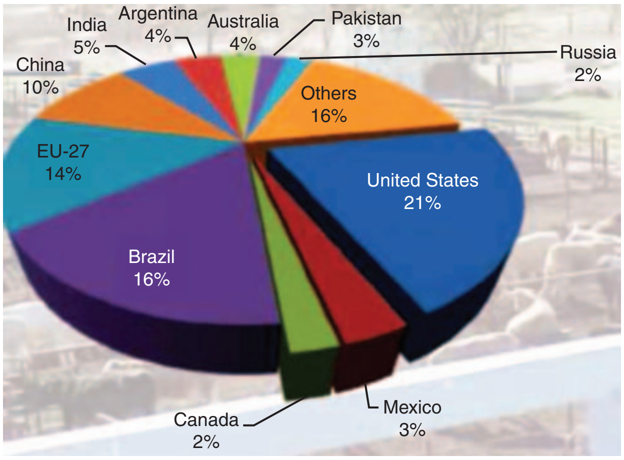


Figure 4.1: World beef production by country in 2011. Source: Galyean *et al.* (2011).

The southern beef production system (Chapter 10) comprises smaller farm holdings. Many of these farms have areas sown with improved pasture and fodder crops to sustain higher stocking rates and cattle growth rates. Due to the high dependence of cattle on grasslands and pastures and the associated seasonality of pasture quality, supplementary hay or grains are sometimes utilised (Chapter 15) to maintain high growth rates and year-round beef production.

Industry characteristics

Australians consume ~35 kg of beef per capita per annum, which equates to only 0.75 million metric tonnes (Bell *et al.* 2011). Therefore, Australia's beef industry relies heavily on export markets because ~65% of Australia's total beef production is exported as chilled or processed beef (Chapter 2) or as live cattle (Chapter 12) depending on the destined market, averaging 1.3 million metric tonnes per annum (Tozer *et al.* 2010; MLA 2011). The

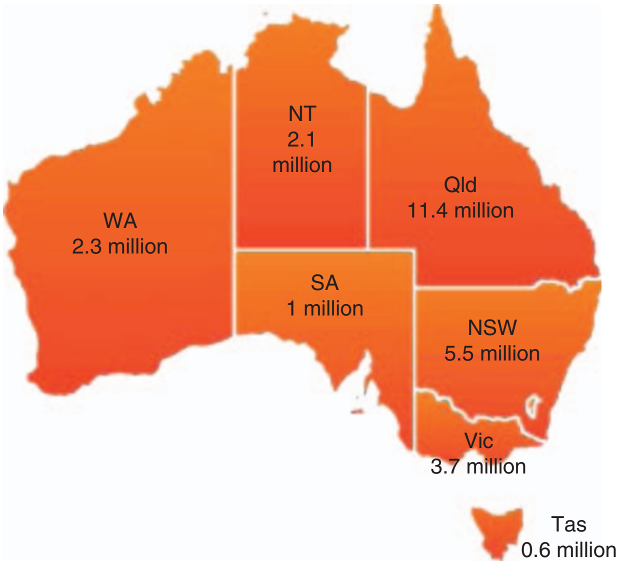


Figure 4.2: Australian cattle population distribution. Source: MLA (2011).

major destinations for Australian processed beef are Japan, the USA and South Korea, while the minor markets are Russia, the EU, Middle East and Chinese Taipei (ABARE 2012). Live cattle export is predominantly to Indonesia, which until recently accounted for over 63% of total live cattle export (Thompson and Martin 2012; Chapter 12).

The beef industry's biggest comparative and competitive advantage is its world-renowned disease-free status, including foot-and-mouth disease (FMD) and bovine spongiform encephalopathy (BSE) (Tozer *et al.* 2010; Galyean *et al.* 2011). Much work must be undertaken to ensure the continuity of this status, as a net loss of AU$18.2 billion is predicted if FMD was discovered in Australia (Tozer *et al.* 2010). Consequently, integrating biosecurity and quarantine services at the state and federal levels through increased public investment is desirable (Johnston *et al.* 2012; Chapter 13). Australian beef producers are also adapting production methods to meet export market requirements. For example, since the ban on growth promotants by the EU Common Agricultural Policy and a major Australian supermarket chain, some Australian producers have limited their use of Australian-sanctioned hormonal growth promotants (HGP) (Hunter 2010; Chapter 11). Australian animal welfare consideration and slaughtering practices are also at a high international standard.

A major limitation to Australian beef production is the annual extended dry season in the tropics and subtropics, the poor soil types, the availability of suitable markets (especially in northern Australia) and avoiding land degradation (Bell *et al.* 2011). These challenges can be overcome partially through improvement in cattle feed efficiency and development of breeds more suited to the environment (Chapter 18).

Outlook

Favourable climatic conditions in key beef production regions of Australia have promoted pasture growth and prompted many beef producers to 'rebuild' their herds to early 2000s numbers. This is also prompted by lack of suitable markets for breeder cows in northern Australia since Indonesian restrictions in June 2010. There are projected increases in beef prices and demand in export markets (ABARE 2012). Increases in national herd numbers lead to projected increases in total national beef production (FAO 2011). In general, favourable exchange rates and improvement in the economies of major export markets are major boosts to all beef-exporting countries, including Australia.

New Zealand

Background

New Zealand's beef industry is export-focused. The current national herd of 3.9 million head contribute only 1% of total global beef production, but it equates to 8% of the total global beef trade (Bell *et al.* 2011). NZ's beef herd comprises European beef cattle breeds (Table 4.2), although a significant contribution is made from the dairy industry in the form of culled cows and bull calves (B+LNZ 2012a).

The majority of NZ beef is produced in mixed farming systems, where beef cattle are finished on pasture along with other livestock such as sheep, dairy or deer (B+LNZ 2012a). Pasture finishing systems are optimal in NZ's temperate climate, with perennial pastures providing a low-cost and low-input feed base. However, finishing beef cattle on a pasture-based system takes longer than in

Table 4.2: New Zealand national beef herd breed composition

NZ beef cattle breeds	% total beef herd
Angus	23
Angus × Hereford	10
Hereford	9
Friesian × Hereford	4
Friesian	19
Mixed	30
Others	5

Source: B+LNZ (2012a).

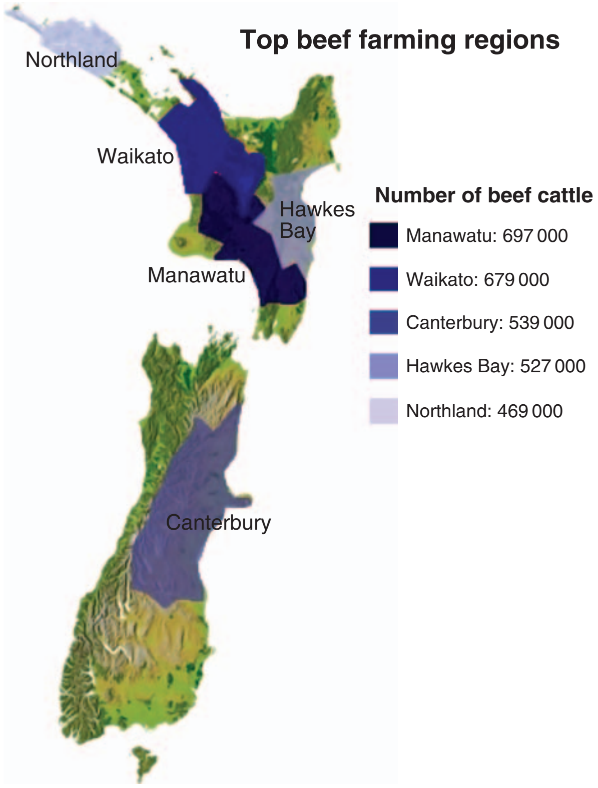


Figure 4.3: Beef-producing regions in New Zealand. Source: Greenstone Recruitment (2012).

more intensive lot-feeding finishing systems because it takes the animals longer to reach the desired slaughter weight. Beef production is primarily located in the North Island, accounting for ~73% of the national herd (B+LNZ 2012b; Fig. 4.3).

Industry characteristics

The USA is NZ's main beef export market in terms of both value (47%) and volume (51%) (Bell *et al.* 2011; B+LNZ 2012b). However, NZ also has market interests in Japan (9% of total beef exports), South Korea (8%), Taiwan (6%), Canada (6%) and Indonesia (9%) (B+LNZ 2012b). NZ's disease-free status from many significant cattle disorders, including FMD and BSE, has been at the forefront of promoting continued access to these markets. Its international reputation for safe, high quality, pasture-fed beef aids this cause. However, the comparative strength of the NZ dollar in 2012 was hurting this market share, as is Indonesia's planned shift to a self-sufficient beef industry by 2014 (B+LNZ 2012b).

NZ beef industry's export position is moving towards production intensification and feedlotting (White *et al.* 2010). However, this development is facing stiff resistance from the NZ public on the basis of environmental concerns and negating many of the current beef production advantages in NZ, particularly its low-input and low-cost pasture system.

A concern to NZ beef production is its heavy reliance on and interrelationship with other livestock industries. Competition for land between sheep, dairy and beef production is great, and is increasing land prices (B+LNZ 2012a). High contributions from the dairy industry to beef production have implications for end use and available markets, e.g. ground beef *v.* prime table beef production (Bell *et al.* 2011).

Outlook

Long-term trends indicate an 8% decline in beef cattle numbers since 2001 (B+LNZ 2012a), suggesting that the NZ dairy industry is outcompeting beef. This highlights the dependency of NZ beef on the dairy industry, with any restructuring in the dairy industry directly impacting NZ beef interests by affecting cattle contributions.

Geographical isolation from the rest of the world and active border control policies make beef production in Australia and NZ unique in their disease-free credentials and high quality standards. However, there are differences between the two countries. In Australia, beef, dairy and sheep farming are usually distinct industries, while sheep complement cattle in most NZ farming systems – only because the wool industry is in decline. In southern Australia, where fat lambs are very profitable, beef and sheep run together as you don't need a lot of infrastructure if wool is not the core activity. NZ's beef production systems are dependent on the dairy industry – a comparative drawback, as they are relegated to secondary status behind competing interests. Bryant and Sheath (1987) classified NZ's grasslands into three groups based on topography: high, hill, and flat to rolling country. The animal husbandry systems in these grasslands range from intensive beef, dairy or sheep production on the lowlands reputed to be very productive, through to cattle and sheep only extensive farming systems in the high country. Charteris *et al.* (1998) reported that in NZ's hilly regions, the complementary farming of sheep and beef cattle provides flexibility to switch the mix depending on preferences and economic conditions dictated by the market.

A comparative classification of production systems, herd sizes, age at weaning, cattle types and breeding management between beef-producing countries is presented in Table 4.3.

Table 4.3: Comparison of animal husbandry and industry characteristics between major beef-producing nations

	Argentina	Australia	Brazil	Canada	EU	India	NZ	USA
Herd size	Medium	Large and medium	Medium	Large	Small to medium	Small	Small	Large
Age at weaning	Early	Early and late	Early	Early	Early and late	Various	Early and late	Early
Breeding	Intensive	Highly intensive	Intensive	Intensive	Intensive	Non-intensive	Highly intensive	Intensive
Farming enterprise	Beef	Beef/mixed	Beef	Beef/mixed	Mixed/beef	Nondescript	Dairy/mixed	Beef
Production system (main)	Pasture-fed	Pasture-fed	Pasture-fed	Grain-fed	Mixed	Miscellaneous	Pasture-fed	Grain-fed
Finishing method (main)	Grain	Grain	Grain	Grain	Pasture	Neither	Pasture	Grain
Breed origin	Beef specialist	Beef specialist	Beef specialist	Beef specialist	Dairy	Mixed	Dairy	Beef specialist
Cattle type	Temperate	Temperate and tropical	Tropical	Temperate	Temperate	Tropical	Temperate	Temperate and tropical
Diseases	FMD	n/a	FMD	BSE and FMD	BSE and FMD	?	n/a	BSE and FMD
Disease controls	Vaccination	Biosecurity	Vaccination	Vaccination	Vaccination	Education	Biosecurity	Vaccination
Traceability scheme	Mandatory	Mandatory	Mandatory	Voluntary	Mandatory	None	Mandatory	Voluntary
GHP usage (as per EU)	Yes	Yes	Yes	No	Yes	No	Yes	No
Govt involvement	High	Low	High	Moderate	High	Low	Low	Moderate
Future challenge (main)	Herd rebuilding	Climate change	Environmental image	Export market expansion	Rural social welfare	Government policy	Competition with dairy	Animal welfare and environmental impact

This table was constructed simultaneous to chapter and used references available in text.
Herd size: small = 1–25, medium = 26–50, large = >50. Age at weaning: early = <5 months, late = 7–8 months.

India

Background

India has the largest national cattle herd in the world (FAO 2012; Sirohi and Michaelowa 2007), with the incomes of over 70 million rural Indians supplemented by livestock production interests (Vinod *et al.* 2003). India's national herd comprises ~10% of all recognised cattle breeds in the world (Singh 2002), but the majority (80%) of these cattle are of nondescript breeds. The primary factor for the dominance of nondescript breeds is the small herd size and scale at which cattle are farmed, with ~90% of Indian cattle kept in herds of one to three animals.

Indian cattle are multi-purpose because they are used for milk, draught and organic manure production (Singh 2002). They are fed crop residues, native herbage and other roughages. Typically, neither feed supplementation nor pasture grazing is practised due to the high cost of feed concentrates and the scarcity of grassland. It is only 'once an animal is spent and useless that it is slaughtered' (Singh 2002). This is the primary source of cattle used in the beef industry, hence India's inability to play an important role in global beef exports despite it being the country with most cattle.

Table 4.4: Number of cattle slaughtered, average yield per animal and total beef production between 2010 and 2011 in the five highest beef-producing states of India

State	No. cattle slaughtered ('000)	Average yield (kg)	Total beef produced (KT)
Kerala	540	98	53
Maharashtra	259	127	33
Meghalaya	251	88	22
Bihar	514	41	21
Nagaland	164	125	20

Source: Department of Animal Husbandry Dairying and Fisheries (2012).

Industry characteristics

Low production costs arising from non-intensive beef production and strong demand for cheap beef in India's neighbouring South-East Asian countries has provided India with a lucrative beef export market (FAO 2011). Exports to Indonesia are considerable but basically illegal because of the FMD status of the national herd in India. Recent focus on expansion within India's dairy sector has resulted in a greater turnoff of 'unwanted' male calves, thus boosting the beef industry (Barrett 2011).

Government intervention to genetically improve India's cattle population is developed and supported through the Central Cattle Development Organisations. These include several central cattle-breeding stations, a central frozen semen production and training institute and four central herd registration units tasked with breeding genetically superior cattle for India's increasing demand for frozen semen (Department of Animal Husbandry Dairying and Fisheries 2011, 2012). Exotic sire breeds are being introduced into India's national herd to improve productivity by crossbreeding with highly productive European cattle breeds (Sirohi and Michaelowa 2007).

Over the last three decades, the Indian government has subsidised the public delivery of these livestock developments and services to cattle farmers. This has the direct benefit of aiding farmers who could not otherwise afford to pay for these services (Vinod *et al*. 2003). As a consequence, India seems well-placed to strategically expand and potentially become the fourth-largest beef exporter in the world. However, doing so sustainably requires bolder attempts at overcoming the limitations of its beef industry.

The main limitation of India's beef industry is the poor genetic base and low productivity of the national herd (Tables 4.4, 4.5). These problems are exacerbated by substandard feeding and management of feed resources, uncontrolled and unmonitored breeding, and weak information-sharing pathways between scientific research institutes and farmers (Department of Animal Husbandry Dairying and Fisheries 2012; Singh 2002). The lack of cohesion between Indian states and the absence of a national policy on the legality of cattle slaughter is the major limitation to India's beef industry.

Cattle slaughter is a highly volatile and emotional issue in India because of religious beliefs about the avowed sacredness of cows in the majority Hindu population.

Table 4.5: Beef production quantity (tonnes), 2005–2010

	Year					
Country	2005	2006	2007	2008	2009	2010
Argentina	3 130 800	3 033 600	3 223 700	3 131 900	3 378 460	2 630 160
Australia	2 161 960	2 077 070	2 226 290	2 131 910	2 123 960	2 108 290
Brazil	8 592 000	9 020 000	9 303 000	9 024 000	9 395 000	9 115 000
Canada	1 464 460	1 327 200	1 278 580	1 288 070	1 251 930	1 272 260
China	5 356 644	5 499 440	5 845 638	5 840 656	6 060 069	6 243 716
EU	8 052 199	8 100 489	8 179 459	8 032 334	7 927 943	8 085 987
Mexico	1 557 710	1 612 990	1 635 040	1 667 140	1 704 990	1 744 740
New Zealand	651 772	642 888	632 378	634 558	637 030	635 289
USA	1 1196 000	1 1862 800	11 979 400	12 163 000	11 891 100	12 045 800
World	59 728 337	61 782 421	63 247 716	63 374 413	64 032 024	64 275 698

Source: FAO (2012).

Consequently, domestic beef consumption is minimal and several Indian states legally protect cattle from slaughter, while other states permit only licensed cattle slaughter (Chigateri 2011). This has prompted the growth in an underground beef trade: cattle are transported from states with slaughter bans to unlicensed slaughterhouses (Chigateri 2011). The illegality aside, these practices disrupt an already poorly organised beef marketing system.

Outlook

A future risk to Indian beef production is predicted climate change (Sirohi and Michaelowa 2007). This is expected to directly affect cattle by increased heat stress, particularly in susceptible crossbred cattle, and reduced productivity. Climate change is predicted to promote the undesirable activity of blood-sucking ticks like *Boophilus microplus*, *Haemaphysalis bispinosa* and *Hyalomma anatolicum*, causing negative production and animal welfare issues (Sirohi and Michaelowa 2007). However, India's immense cattle herd population, relatively low production costs, increasing government assistance to resource-poor farmers and scope for improvement, augur well for the future. Projected strong economic growth would permit future funding injections to overcome identified industry limitations. Increased affluence presents the opportunity for cultural change and exchange with other cultures, particularly the Western lifestyle, that is increasingly accepted in Indian society, with a potential to stimulate increased domestic beef consumption (Fu *et al.* 2012). This will largely depend on India's beef industry primarily adopting secularised government policy on cattle slaughter.

Argentina

Background

Argentina has a long history of beef production and is the second-largest producer in Latin America, after Brazil (Arelovich *et al.* 2011; Scholtz *et al.* 2011; Chapter 6). Argentina's national herd is primarily based on British cattle breeds (Scholtz *et al.* 2011), as Aberdeen Angus and Hereford were introduced in the late 1800s. Other European breeds such as Charolais and Limousin arrived later in the 20th century (Arelovich *et al.* 2011). The national herd is composed of 10% dairy cows, 50% Angus, 25–30% Hereford; the remainder are generally Brahman or Brahman-crosses with Angus or Hereford (Mathews and Vandeveer 2007).

Table 4.6: Cow, heifer, steer, bull, total cattle population (millions) and percentage change from previous year over four consecutive years in Argentina

Year	Cows	Heifers	Steers	Bulls	Total	Variation (%)
2008	23.7	8.2	4.8	1.2	57.5	
2009	22.4	7.8	4.6	1.1	54.4	–5.5
2010	20.5	7.2	4.1	1.0	48.9	–10.1
2011	20.0	7.3	3.6	1.0	47.9	–2.0

Source: Arelovich *et al.* (2011).

Until the 1990s, all Argentine beef cattle were fed from weaning to finishing on native and cultivated pastures with only occasional grain supplementation. In the 2000s, however, many traditional beef producers have realigned their focus on grain and oilseed cropping to exploit high world prices because the economic returns from these pursuits are much better than from beef production. It is the same story worldwide: beef cattle can only really be run on land which is not suitable for other agricultural pursuits (Mathews and Vandeveer 2007). This resulted in the loss of much pastureland and the adoption of feeder cattle production methods. The low domestic corn prices and availability of energy-rich rations are large contributing factors in the intensification of feeder cattle production (Joseph 2011; Steiger 2006). However, cropping was associated with a decline in the national herd population and composition due to the reduction in breeder cows: this led to a shortage of calf supply to the feeder production system. Breeder cows were being run on crop residues and more marginal land, thus calf production became a by-product of cash cropping (Arelovich *et al.* 2011; Steiger 2006; Table 4.6). In 2011, Argentine beef cattle in feeder production systems were typically finished using grains, and corn or sorghum silage during their last 100–150 kg liveweight gain (Joseph 2011). However, due to their initial growth on pasture, they could still be marketed as grass-fed beef.

Industry characteristics

The Argentine government tightly regulates the beef industry because Argentina has the highest domestic consumption of beef per capita in the world, averaging 65–70 kg per capita per annum between 2006 and 2009 (Joseph 2011). Domestic demand is relatively inelastic, hence the government uses beef as a means of controlling domestic inflation and political stability (Steiger 2006). Beef was noted as having played a pivotal role in

Argentina's recovery from the financial crisis of the early 2000s (Steiger 2006).

Since 2010, Argentina managed the calf shortage by establishing and enforcing minimum slaughter weights at 280 kg liveweight and 165 kg bone-in carcasses, with Resolutions 13/2010 and 88/2010 (Arelovich *et al*. 2011). Beef price control was introduced in 2010, with beef wholesale and retail prices increasing by ~30% after three years without change (FAO 2011). This regulation of the domestic beef industry extended to exports, with significant taxes imposed.

Argentina's major export markets include the EU, the Russian Federation, Israel, Chile and the USA (Joseph 2011; Mathews and Vandeveer 2007). Of these, Argentina's export to the EU has been the most valuable since 2003 when the EU became a net importer of beef, receiving large volumes of out-of-quota beef for which a high duty is paid (Steiger 2006). To retain market share, Argentina's slaughterhouses and retail outlets maintain EU standards (Mathews and Vandeveer 2007). The Russian Federation, however, imports the greatest volume of Argentine beef (Mathews and Vandeveer 2007), making its interests key. Aiding the retention of these export markets is Argentina's current BSE-free status. However, intermittent problems with FMD have negated many attempted inroads into the lucrative Asian markets (Mathews and Vandeveer 2007).

The Argentine beef industry's main disadvantage is its exposure to climatic constraints, natural resource deterioration, slow adoption of emerging innovations and production systems, export and economic volatility, and vulnerability of feeder production systems to changes in grain and oilseed prices (Arelovich *et al*. 2011; Mathews and Vandeveer 2007; Steiger 2006). To overcome these disadvantages and promote a positive international opinion of Argentine beef, drastic steps are needed in preventing disease spread, desertification and degradation of pasturelands and the recovery of large deforested areas (Arelovich *et al*. 2011). Since 2007, animal identification tags have been compulsory and they are expected to be herd-wide by 2016 (Mathews and Vandeveer 2007) in a bid to improve beef traceability.

Outlook

Argentina's beef industry was projected to expand from 2012 to 2020 (Clayton 2011; Mathews and Vandeveer 2007). However, expansion will be slow due to the limited number of breeder cows and calves, and the need to rebuild the national herd. Domestic consumption is forecast to increase only marginally over this period, as it is still recovering from financial crisis (Joseph 2011). Argentina will likely continue to be a main beef-producing country and net exporter.

Brazil

Background

Over 6.8 million Brazilians are directly or indirectly employed by the beef industry (Ferraz and de Felicio 2010; Chapter 6). The leading beef exporter in the world is Brazil. It is also the second-largest global beef producer, with the largest commercial beef cattle herd in the world (Scholtz *et al*. 2011; Ferraz and de Felicio 2010). Brazil's national herd consists primarily of *Bos indicus* (Zebu) cattle breeds whose origins can be traced back to fewer than 7000 purebred animals imported from India during the 19th and 20th centuries. Nellore, both standard/horned and polled, is the major Zebu breed in Brazil, followed by Guzerat and Gir breeds respectively (Ferraz and de Felicio 2010). Only a small fraction of the Brazilian cattle herd is crossbred (Steiger 2006).

Two methods of beef cattle finishing are employed by Brazilian producers (Table 4.7). The method used by more than 83% of producers is the traditional pasture-fed system (Ferraz and de Felicio 2010). However, as in Argentina, an expansion of the more profitable cash-cropping component in the traditional cow–calf

Table 4.7: Beef cattle finishing schemes in Brazil's beef industry

Method	Maturing	Description
Feedlotting	Early	Generally, crossbred animals are sent to feedlots at 8 months of age and 240 kg bodyweight. The feedlots utilise grain rations comprising sorghum and maize, and silage from grass, sugarcane and agricultural crop residues and by-products
	Early	Weaned purebred and crossbred animals are pasture-fed until 18–24 months, when they are introduced to feedlotting
Pasture-fed	Slow	Cattle are maintained on pastures of variable quality, slaughtered at 30–43 months at an average of 450–500 kg bodyweight. *Bos indicus* and crossbreds are the main cattle breeds

Source: Ferraz and de Felicio (2010).

pastureland from 2003 to 2011 placed this system under competitive pressure (Millen *et al.* 2011). Feedlot finishing systems are gaining momentum in Brazil. Feedlots allow comparably younger cattle (Table 4.7) to reach slaughter weight quicker than their pasture-fed equivalents, with the latter group's average slaughter age being four years old (Ferraz and de Felicio 2010). However, due to the cheaper production costs associated with pasture feeding, feedlots are generally utilised only during periods of pasture scarcity in the dry season. Cattle are kept in feedlots for only short periods of ~70 days to minimise production costs (Millen *et al.* 2011). Feedlots are primarily located in regions with concentrated cow–calf and grain producers, particularly the states of São Paulo, Goiás, Mato Grosso and Mato Grosso do Sul (Millen *et al.* 2011).

Industry characteristics

About 60% of Brazil's beef exports go to the EU (Steiger 2006). Brazil also maintains several other export markets in the Middle East, Russian Federation, Asia, Chile and the USA (Millen *et al.* 2011; Silva 2012). The export of fresh beef experienced the greatest growth relative to other beef products between 1994 and 2006 (Ramos Xavier Pereira *et al.* 2011). Brazil also supports a strong domestic market with per capita consumption of ~37 kg of beef per annum. This equates to an annual consumption exceeding 7.03 million tonnes and ~72.5% of Brazil's beef production is required to meet the demand (Ferraz and de Felicio 2010).

The two methods of beef cattle finishing used in Brazil have the following characteristics:

1. the pasture-fed system is the traditional system used by more than 83% of producers. It is under pressure from competing and more profitable land uses, such as cash-cropping;
2. feedlotting, enabling younger cattle to rapidly reach slaughter weights. Located in regions with concentrated brood cow and grain producer numbers, particularly the states of São Paulo, Goiás, Mato Grosso and Mato Grosso do Sul (Ferraz and de Felicio 2010; Millen *et al.* 2011).

There are vast farmlands, relatively cheap labour in pasture-fed and finished cattle systems, and many trade barriers have been removed (Millen *et al.* 2011). This has permitted the establishment of large Brazilian beef corporations, which afford economies of scale. Favourable exchange rates and intensive marketing campaigns by Brazil's beef-packing companies highlighting its BSE-free status (Ferraz and de Felicio 2010) in the 2000s furthered Brazil's beef industry interests (Steiger 2006). Brazil's beef-packing companies and corporations were well-positioned financially and many were actively acquiring international meat and feedlot companies abroad around 2010 (Millen *et al.* 2011).

However, there are several key challenges. The Amazon deforestation remains at the forefront of strong global opinion and environmental concern, which significantly weakens Brazil's beef image (Millen *et al.* 2011; Steiger 2006). This issue is compounded as national herd expansion without deforestation is restricted by competition between beef and more profitable alternative land uses such as soybean and sugar production (Steiger 2006). This places pressure on domestic inflation, as domestic beef demand is inelastic and leads to increases in land prices. To combat these effects the Brazilian government subsidises smallholder beef producers, albeit to support social objectives rather than to encourage production efficiencies.

Since 2001, the Association of Brazilian Beef Exporters (ABIEC) has been promoting the brand 'Brazilian Beef' as a natural, grass-fed, environmentally friendly and healthy product (Steiger 2006). This has helped overcome FMD image issues. Only 16 out of the 27 states in Brazil are considered FMD-free (Millen *et al.* 2011). This has restricted Brazilian beef expansion into Asian export markets and contributes to deleterious fluctuations in cattle prices (Steiger 2006). Since identifying FMD, the industry has adapted to rear over 80% of the national beef herd in FMD-free states (Ferraz and de Felicio 2010). The vaccination program to ensure FMD-free status increases production costs. Brazil has ensured EU markets remain accessible through mandatory introduction of a traceability scheme throughout its supply chain, banning β-antagonists, antibiotics and growth implants, and maintaining slaughter hygiene standards to EU requirements (Millen *et al.* 2011).

An area for improvement is the Zebu cattle breeds used by Brazil's beef industry. Zebu cattle are renowned for their low-quality beef, especially regarding tenderness (Ferraz and de Felicio 2010), and slower feedlot growth rates compared to crossbreds, as feed intake is 6–8% lower (Millen *et al.* 2011). Consequently, the Brazilian government is subsidising semen imports of Red Angus, Angus, Simmental, Limousin and other European beef breeds to cross with the local Nelore cattle (Steiger 2006). This has been well-received, with beef producers adopting AI more quickly than the dairy industry has (Steiger 2006) – an active search for industry improvement.

Outlook

Brazil's beef industry is projected to remain the world's leading beef exporter due to the expansion of national herd numbers and production due to continuous government subsidies, genetic and pasture improvement, stabilisation of cattle prices, and flexibility to meet EU specifications (Silva 2012; Chapter 6). Both export and domestic market demand are forecast to increase due to increased industry competitiveness and domestic economic growth encouraging greater consumer purchasing power (Millen *et al.* 2011; Silva 2012). However, combating environmental concerns is fundamental to the long-term success of Brazil's beef industry.

Canada

Background

Canadian beef is mainly produced on pasture on ranches (Vergé *et al.* 2008). Intensification of production systems, similar to the USA, during 1990–2010 increased cattle herd sizes. Presently, cow–calf operations are based on ranches, with calves bred and raised on pasture before being sold as feeders, at ~4–6 months old (Vergé *et al.* 2008), into either backgrounding or feedlot systems.

Cow–calf systems constitute ~93% of Canada's national herd (Cutts *et al.* 2012). The majority of calves produced in these systems are finished in feedlots using intensive, energy-rich grain diets (Brester and Clause 2011). Canadian feedlots are mostly individually owned rather than corporation owned. The feedlots are large, with over 90% of grain-fed beef cattle kept in feedlots with capacities greater than 1000 head (Vergé *et al.* 2008).

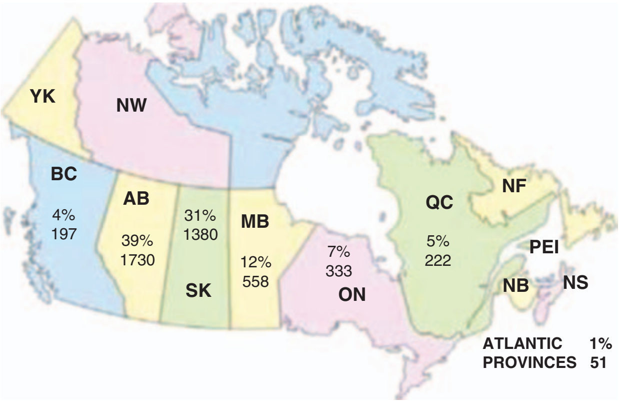


Figure 4.4: Canadian national beef herd distribution ('000 head). Source: CBC News (2012).

Canada's beef industry is predominantly located in the Prairie provinces (Fig. 4.4), with Alberta running the majority of cattle (AAFC 2011; Mitura and Di Piétro 2004). Beef producers in Alberta generally run cattle in large holdings of more than 100 head, with a third of Alberta's beef production emanating from 70 beef operations contributing 14% or CAN$6.2 billion to Canada's annual total farm receipts (AAFC 2011).

Industry characteristics

In May 2003, the Canadian beef industry experienced major setbacks following the discovery of BSE. More than 40 countries imposed immediate restrictions on the importation of Canadian beef products (McLachlan and Yestrau 2009). Most damaging was the US closure of its border to Canadian beef products and movement of live cattle for 18 months. Prior to the BSE menace, the USA represented 75% of Canada's total export market (McLachlan and Yestrau 2009; Ward *et al.* 2009). Fortunately, Canada's export market began to recover by 2009, with 8% growth between 2009 and 2010 as the USA and Mexico increased their imports by 5% and 1% respectively (AAFC 2011). Supporting this recovery were federal and provincial BSE Recovery Programs which compensated producers for lost profit and promoted the adoption of holistic BSE management strategies. The Canadian Food Inspection Agency promoted Canadian red meat globally, focusing on its wholesomeness and safety (AAFC 2011).

Canadian domestic beef consumption is contracting. Annual beef consumption per capita fell from 17.4 kg during the mid 1980s to 12 kg in 2012 (Serecon Management Consulting 2005; Twine and Rude 2012). Focus on developing ready-to-eat and convenient beef-based meals is being used to reverse this trend (Serecon Management Consulting 2005). The decrease was thought to be associated with a recession-induced decline in incomes affecting consumer behaviour and available preparation times (Twine and Rude 2012).

A major factor limiting industry recovery is the trade relationship between Canada and the USA, which is tested by:

1. a relatively strong Canadian dollar;
2. the USA introducing mandatory country-of-origin labelling to promote consumer discrimination against imported beef products;
3. restrictions on trade beef cattle age and the removal of specific risk material during slaughter to eliminate BSE concerns, which increase production costs (Twine and Rude 2012; Ward *et al.* 2009).

While these have negative connotations, they have also prompted investment in expanding Canada's slaughtering capacity and export markets (Twine and Rude 2012).

Outlook

With economic recovery, Canada's beef industry is projected to grow from 2012, albeit slowly as the national herd must progress through a rebuilding phase (USDA 2012a). Beef replacement heifer numbers increased by 4.3% in 2011, indicating a reinvigoration of the national herd with younger cattle (Cutts *et al*. 2012). In 2004 the export market was identified as the primary area of beef industry growth, with increases evident in live cattle and beef product export (Mitura and Di Piétro 2004). This reliance on export markets suggests cautious optimism in Canada's future beef industry. However, domestic consumption is expected to recover more slowly than exports, as many consumers have replaced beef with other meat types and are consuming alternative diets. The latter trend is linked with the rising levels of Asian immigration to Canada and the preference of Asians for fish and pork (Serecon Management Consulting 2005; Chapter 1).

European Union

Background

Historically, the EU is a major beef exporter. However, the dissolution of many government subsidies, incentive policies and reduced production prompted a reversal to net importation in the 2000s (Zjalic *et al*. 2006). EU beef consumers hold a strong influence over how cattle are managed and processed. Today's EU beef consumers enforce animal nutrition and husbandry, meat hygiene and safety, and environmental restrictions on any beef permitted access to the EU market (Ahola 2008; Hocquette and Chatellier 2011). In many cases, this is conveyed to producers in the form of government involvement in EU policy formulation and financial incentives to regulate beef production.

The EU cattle population was ~88 million head in 2012, with numbers increasing slightly from 2009 following a downwards trend recorded since the 1980s (Peck 2009). The beef herd is concentrated in four EU member states: France (34% of total EU herd), Spain (16%), Ireland (14%) and the UK (13%) (Hocquette and Chatellier 2011). Dairy cattle contribute up to two-thirds of the EU cattle herd, thus coupling EU dairy and beef industries (AGRI/IPTS 2011; Hocquette and Chatellier 2011; Peck 2009).

EU beef is typically produced on two types of farms:

1. dairy farms, where beef production is a by-product of milk production;
2. specialised beef farms with a cow–calf production focus (Hocquette and Chatellier 2011; Zjalic *et al*. 2006).

In specialised beef farms, the system varies depending on geographic location. Western Europe generally produces beef in pasture-fed systems, whereas Central–Eastern Europe and the Mediterranean include beef production in cropping systems. The pasture-fed systems characteristically use specialised beef breeds and unwanted male dairy calves, which grow slowly to heavier slaughter weights with stronger meat flavour (Zjalic *et al*. 2006). Cereal-based systems use beef breeds, crossbreds and dairy calves more intensively producing lighter animals with less intense flavour (Zjalic *et al*. 2006). Beef producers select farm type according to market demand and the production capacity of farms (Zjalic *et al*. 2006).

Industry characteristics

The EU beef industry contributes 10% of the total value of EU agricultural production. In 2010, beef represented 21% of total meat consumed in the EU, or 16 kg per capita per annum. However, EU demand for beef was on a slow, steady decline in the 2000s, due to several factors:

1. economic difficulty;
2. disease crises, including BSE outbreaks, undermining consumer confidence (Zjalic *et al*. 2006);
3. volatile feed prices;
4. the extension of tariff-free importation quota for high-quality imports from Canada, New Zealand and Uruguay (FAO 2011);
5. uncompetitive production systems compared to other global producers of alternative meat types such as poultry and pork (Hocquette and Chatellier 2011);
6. decoupling of subsidy payments for milk production, thus weakening calf resources (Ahola 2008; FAO 2011). Consequently, all major EU members' cattle herd numbers contracted, with the exception of Poland (Rabobank International 2011).

EU policies aim to preserve the beef industry. For instance, the Common Agricultural Policy (CAP) undertook reformations in 2003 to account for food safety and environmental concerns surrounding beef production (Zjalic *et al*. 2006). CAP also provides an insurance of farm income and a minimum income for beef producers, thus ensuring the sustainability of rural communities and other social considerations (Hocquette and Chatellier 2011; Zjalic *et al.* 2006). Animal welfare is also protected by EU policy, with the Amsterdam Treaty of 1997 identifying animals and stipulating the inclusion of welfare practices in farming (Hocquette and Chatellier 2011).

The EU beef industry in 2012 was bolstered as a result of the exchange rate and the shortage of beef supply from Latin American producers. This opened up beef market opportunities in the Russian Federation and the Middle East, especially Turkey (AGRI/IPTS 2011; FAO 2011). After Turkey opened its market to beef imports in late 2010, EU beef exports increased by 95% up to 2011 (Rabobank International 2011). This export surge was attributable primarily to the 36% and 30% growth in total exports to the Russian Federation and Turkey, respectively, that aided in sheltering the industry from the effects of higher feed costs and overcapacity (Rabobank International 2011).

Outlook

The EU beef industry is projected to decline steadily over the coming decades (AGRI 2012). This is driven by an increase in meat imports, a weakening euro undermining competitiveness, the abolition of the milk quota scheme and a decline in domestic beef consumption. Consequently, it is projected that by 2020 EU beef exports will contribute only 1% to domestic production and domestic beef consumption will decline by 0.8%, compared to 2010 figures (AGRI/IPTS 2011). Therefore, the continuous decrease in the EU cattle herd population observed since 2008, averaging ~1.1% per annum, is forecast to continue (AGRI 2012). This decline is projected to be steady and controlled, which will allow the EU to remain a global driver for imported beef quality to meet its standards.

USA

Background

Although the US national beef herd is only the fourth largest, exceeding 90.2 million head (Brester and Clause 2011), it is the world's largest beef producer (Chapter 5). In 2011, 7% of total US farm-gate agricultural sales (of over US$45 billion) was generated by cattle and calf production (Brester and Clause 2011).

US beef production is characterised by three interlinked operational components. The cow–calf component produces calves to be used in the other components. Cows maintained on ranches rely heavily on pasture and forages (Galyean *et al.* 2011). Calves are typically weaned in autumn at liveweights of 200–300 kg (Brester and Clause 2011), and sold to stocker/backgrounders or feedlots. Stocker/backgrounders finish weaners using non-intensive methods. The average US beef herd is only 50 head, although 400 head is generally considered the lower threshold of this production system for commercial viability (Brester and Clause 2011). Feedlots, on the other

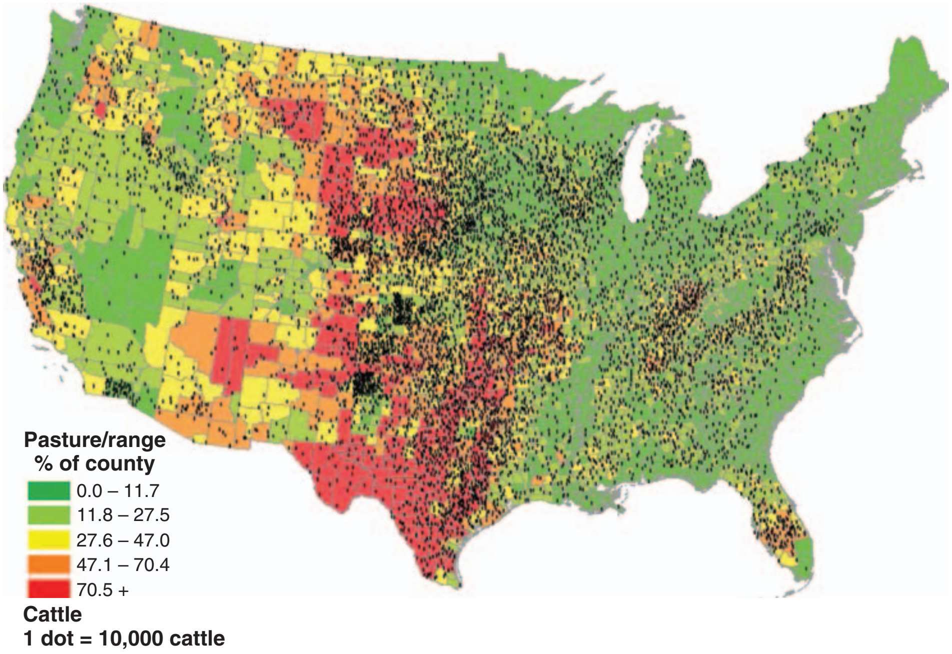


Figure 4.5: Distribution of the US cattle herd. Source: USGCRP (2009).

hand, intensively finish weaners using energy-rich, grain-based diets, usually corn, sorghum or barley. Feedlots finish cattle for three to seven months, and are considered the most efficient beef production system in terms of energy and land use production per animal because growth rates are 1–1.8 kg per day (Galyean *et al.* 2011).

The US beef herd is spread nation-wide, but Texas, Oklahoma, Missouri, Nebraska, South Dakota, Kansas, Montana, Kentucky, Tennessee and Florida together account for 59% of the national herd (Brester and Clause 2011; Fig. 4.5). Most (65%) feedlots are located in Texas, Nebraska, Kansas and Colorado, with a combined capacity of over 16 million head (Brester and Clause 2011). The majority of feedlots are corporately owned, with cattle processed as a commodity (Galyean 2010).

Industry characteristics

The main US beef export markets are Mexico, Canada, Japan, South Korea and the Pacific Rim, which purchase high-quality grain-fed US beef (USDA 2012c). In terms of value, Canada is the largest export market. The discovery of BSE in 2003 resulted in the restriction of US exports into Japanese and South Korean markets. However, those markets reopened in 2012 and US exports are increasing due to favourable exchange rates.

Domestic consumption of beef is ~50% in the form of ground beef and 50% as meat cuts. Annual consumption is ~26 kg per capita, which has increased by ~10% from 1996–2011 (Brester and Clause 2011). The inclusion of 'lean finely textured beef' is permitted in certain ground meat products but has met consumer resistance due to the negative connotation associated with the 'pink slime' (USDA 2012b). Consumer concerns over animal welfare and food safety issues and use of antibiotics and growth promotants have resulted in increased demand for organic beef (Galyean *et al.* 2011).

To meet the high demand for weaners and counter seasonal calf availability, the USA imports feeder cattle from Mexico to ensure continuous production (Brester and Clause 2011; Galyean *et al.* 2011). It also imports grain-fed cattle from Canada and grass-finished beef from Australia, New Zealand and Latin America (Brester and Clause 2011). This is especially important with the US national beef herd decreasing from 2000–2011 (Galyean *et al.* 2011), with drought in major grazing areas in 2011 negating rebuilding efforts in the short term (FAO 2011).

Due to the diverse climatic regions where cow–calf production occurs, a variety of cattle breeds is required. However, the existence of numerous cattle breeds can contribute to beef product inconsistencies (Brester and Clause 2011). Alliances between feedlots and cow–calf producers should provide further opportunities to apply genetic selection tools, improve beef breeds and aid animal identification and traceability (Galyean *et al.* 2011). The US beef industry lags behind other countries in the adoption of traceability systems, with the federal government supporting voluntary rather than mandatory animal tracing systems (Brester and Clause 2011). Many air and water quality regulations have been introduced to address public concerns about the environment, as well as comprehensive nutrient management plans for feedlots (Galyean 2010; Galyean *et al.* 2011).

Outlook

The USA is projected to increase beef imports, especially lean beef from Australia and New Zealand, until 2021 (USDA 2012a). It is projected to become the world's largest importer of beef, replacing the Russian Federation, and accounting for 33% of the increase in global imports (USDA 2012a). The US beef industry is expected to enter a rebuilding and expansion phase to meet domestic demand and replenish a low national herd (USDA 2012c). However, severe drought postponed these goals, now expected to start in 2014 (USDA 2012a).

OPERATIONAL PECULIARITIES OF WORLD BEEF PRODUCTION SYSTEMS

- Geographical isolation from the rest of the world and active border control policies make beef production in Australia unique in its disease-free credentials and high quality standards. This is a major competitive advantage.
- Seasonal variability in climatic conditions and the consequent implication for pasture growth and nutrient quality affects beef production in pasture-based beef production systems. Supplementation with grains, silage and conserved forage can be of immense benefit in filling the seasonal feed gap.
- Temperate cattle breeds produce uniquely different beef in terms of meat quality attributes related to tenderness compared to the tropical Zebu breeds. The Zebu breed is more suited to the domestic trade and local consumption.
- Beef production systems dependent on the dairy industry in New Zealand, the EU and USA experience

a comparative drawback as they are relegated to secondary status with the competing interests.

- Treatment of cattle as sacred in some major beef cattle parts of the world, coupled with the extensive system of production, will be counterproductive to beef production in the long term.
- Disease outbreaks in countries proned to BSE, FMD and other beef cattle diseases can tarnish the image and international acceptability of beef, with devastating economic consequences. Production systems must deal with this in a holistic and consistent manner backed by strong government policies.

REFERENCES

AAFC (2011) All about Canada's red meat industry. Agriculture and Agric.-Food Canada. <http//www.4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1184009758250&lang=eng>.

ABARE (2012) *Agricultural Commodities: June Quarter 2012*. Australian Bureau of Agricultural and Resource Economics, Canberra.

AGRI (2012) *Short-term Outlook for Arable Crop, Meat and Dairy Markets*. European Commission.

AGRI/IPTS (2011) *Prospects for Agricultural Markets and Income in the EU 2011–2020*. European Commission.

Ahola JK (2008) Beef production in the European Union: a look into our future? *Beef Magazine*. <http://beefmagazine.com/americancowman/beef-and-business/0513-europe-beef-production>.

Arelovich HM, Bravo RD, Martínez MF (2011) Development, characteristics, and trends for beef cattle production in Argentina. *Animal Frontiers* **1**(2), 37–45. doi:10.2527/af.2011-0021.

Barrett D (2011) Dairy. *Agricultural Commodities* **18**(1), 83–95.

Bell AW, Charmley E, Hunter RA, Archer JA (2011) The Australasian beef industries: challenges and opportunities in the 21st century. *Animal Frontiers* **1**, 10–19. doi:10.2527/af.2011-0015.

B+LNZ (2012a) Compendium of New Zealand: farm facts. Beef + Lamb New Zealand Economic Service, Auckland.

B+LNZ (2012b) New season outlook 2012–13. Beef + Lamb New Zealand Economic Service, Auckland.

Brester G, Clause R (2011) *Commodity Beef Profile*. Agricultural Marketing Resource Centre. <http://www.agmrc.org/commodities__products/livestock/beef/commodity-beef-profile/>.

Bryant AM, Sheath GW (1987) The importance of grazing management to animal production in New Zealand. *Proceedings of the 4th AAAP Animal Science Congress,* February 1987, pp. 13–17. Hamilton, New Zealand.

Burrow HM (2010) Achieving adoption and innovation in Australia's beef industry. *Animal Production Science* **50**, 418–423. doi:10.1071/AN09183.

CBCnews (2012) Cattle industry hurt over *E. coli* recalls, Saskatchewan says. <http://www.cbc.ca/news/canada/saskatchewan/story/2012/10/04/sk-agriculture-e-coli-minister-121004.html>.

Charteris PL, Garrick DJ, Morris ST (1998) New Zealand beef industry structure and opportunities to improve income. *Proceedings of the New Zealand Society of Animal Production* **58**, 228–230.

Chigateri S (2011) Negotiating the 'sacred' cow: cow slaughter and the regulation of difference in India. Democracy, religious pluralism and the liberal dilemma of accommodation. In *Studies in Global Justice*. (Ed. M Mookherjee) vol. 7, pp. 137–159. Springer, Netherlands.

Clayton P (2011) Global beef marketing opportunities. *Proceedings of Range Beef Cow Symposium*, 29 November–1 December. Mitchell, New England.

Cutts D, Dominquez J, Duffy J, Knox S (2012) *Cattle Statistics*. Statistics Canada, Ottawa.

Department of Animal Husbandry Dairying and Fisheries (2011) *Annual Report 2010–11*. Ministry of Agriculture, New Delhi.

Department of Animal Husbandry Dairying and Fisheries (2012) *Basic Animal Husbandry Statistics*. Ministry of Agriculture, New Delhi.

FAO (2011) *Global Market Analysis*. Food and Agriculture Organisation of the UN (FAO), Trade and Markets Division, Rome.

FAO (2012) FAOSTAT. <http://faostat.fao.org>.

Ferraz JBS, de Felicio PE (2010) Production systems: an example from Brazil. *Meat Science* **84**(2), 238–243. doi:10.1016/j.meatsci.2009.06.006.

Fu W, Gandhi VP, Cao L, Liu H, Zhou Z (2012) Rising consumption of animal products in China and India: national and global implications. *China and World Economy* **20**(3), 88–106. doi:10.1111/j.1749-124X.2012.01289.x.

Galyean ML (2010) The future of feedlot beef production. In *Proceedings of the 25th Annual Southwestern Nutrition and Management Conference,* pp. 63–64. University of Arizona, Tucson.

Galyean ML, Ponce C, Schutz J (2011) The future of beef production in North America. *Animal Frontiers* **1**(2), 29–36. doi:10.2527/af.2011-0013.

Greenstone Recruitment (2012) Farming sectors. Map of New Zealand farming regions. <http://www.greenstone-recruitment.co.nz/work-jobs/new-zealand/farming-sectors.php#>.

Hill RA (2012) *Feed Efficiency in the Beef Industry*. John Wiley and Sons, New York.

Hocquette J-F, Chatellier V (2011) Prospects for the European beef sector over the next 30 years. *Animal Frontiers* **1**(2), 20–28. doi:10.2527/af.2011-0014.

Hunter RA (2010) Hormonal growth promotant use in the Australian beef industry. *Animal Production Science* **50**, 637–659. doi:10.1071/AN09120.

Johnston DJ, Tier B, Graser H-U (2012) Beef cattle breeding in Australia with genomics: opportunities and needs. *Animal Production Science* **52**, 100–106. doi:10.1071/AN11116.

Joseph K (2011) *Argentina: Livestock and Products Annual*. US Department of Agriculture, Foreign Agricultural Service.

Mathews KH, Vandeveer M (2007) *Beef Production, Markets, and Trade in Argentina and Uruguay: An Overview*. US Department of Agriculture.

McLachlan SM, Yestrau M (2009) From the ground up: holistic management and grassroots rural adaptation to bovine spongiform encephalopathy across western Canada. *Mitigation and Adaptation Strategies for Global Change* **14**(4), 299–316. doi:10.1007/s11027-008-9165-2.

McRae T (2012) *Australian Cattle Industry Projections 2012*. Meat and Livestock Australia. <http://www.mla.com.au/Prices-and-markets/Trends-and-analysis/Beef/Forecasts/MLA Australian cattleindustry projections-2012>.

Millen DD, Pacheco RDL, Meyer PM, Rodrigues RHM, Arrigoni MDB (2011) Current outlook and future perspectives of beef production in Brazil. *Animal Frontiers* **1**(2), 46–52. doi:10.2527/af.2011-0017.

Mitura V, Di Piétro L (2004) *Canada's Beef Cattle Sector and the Impact of BSE on Farm Family Income*. Agriculture Division, Statistics Canada, Ottawa.

MLA (2011) *Red Meat Market Report: Composition of Australian Red Meat Exports*. Meat and Livestock Australia, Canberra.

Peck C (2009) Feeding the world, challenges and opportunities for the U.S. beef industry. In *Proceedings of the Range Beef Cow Symposium XXI*. Lincoln, Nebraska.

Rabobank International (2011) *Improving but Fragile Outlook for EU Meat Industry*. Food & Agribusiness Research and Advisory.

Ramos Xavier Pereira PR, Jardim Barcellos JO, Federizzi LC, Lampert Vd N, Andrighetto Canozzi ME, Marques PR (2011) Advantages and challenges for Brazilian export of frozen beef. *Brazilian Journal of Animal Science* **40**(1), 200–209.

Rust SR, Abney CS (2005) Comparison of dairy versus beef steers. *Proceedings of Managing and Marketing Quality Holstein Steers*. University of Minnesota Dairy Extension, Rochester, MN. <http//www.extension.umn.edu/dairy/holsteinsteers/pdfs/papers/ComparisonDairyVsBeef_Rust.pdf>.

Schaefer DM (2005) Yield and quality of Holstein beef. *Proceedings of Managing and Marketing Quality Holstein Steers*. University of Minnesota Dairy Extension, Rochester, MN. <http//www.extension.umn.edu/dairy/holsteinsteers/pdfs/papers/YieldAndQuality_Schaefer.pdf>.

Scholtz MM, McManus C, Okeyo AM, Theunissen A (2011) Opportunities for beef production in developing countries of the southern hemisphere. *Livestock Science* **142**(1–3), 195–202. doi:10.1016/j.livsci.2011.07.014.

Serecon Management Consulting (2005) *Canadian Food Trends to 2020: A Long-range Consumer Outlook*. Agriculture and Agric.-Food Canada, Edmonton, Alberta.

Silva JF (2012) *Brazil: Livestock and Products Semi-annual*. US Department of Agriculture, Foreign Agricultural Service.

Singh K (2002) Beef production in India. In *Development Strategies for Genetic Evaluation for Beef Production in Developing Countries. Proceedings of an International Workshop,* 23-28 July 2001. Khon Kaen Province, Thailand. (Eds J Allen and A Na-Chiangmai), pp. 34–39.

Sirohi S, Michaelowa A (2007) Sufferer and cause: Indian livestock and climate change. *Climatic Change* **85** (3–4)**,** 285–298. doi:10.1007/s10584-007-9241-8.

Steiger C (2006) Modern beef production in Brazil and Argentina. *Choices: the magazine of food, farm, and resource issues* **21,** 105–110.

Thompson T, Martin P (2012) *Australian Beef: Financial Performance of Beef Cattle Producing Farms, 2009–2010 to 2011–12*. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Tozer PR, March TL, Perevodchikov EV (2010) Domestic and trade impacts of foot and mouth disease and BSE on the Australian beef industry. In *Proceedings of the 54th Conference of Australian Agricultural and Resource Economics Society*, Adelaide, South Australia.

Twine E, Rude J (2012) Effects of market and policy shocks on the Canadian and U.S. cattle and beef industries. In *Agricultural and Applied Economics Association 2012 Annual Meeting*, 12–14 August. Seattle, Washington.

USDA (2011) Livestock and animals. US Department of Agriculture. <http://www.nass.usda.gov/Statistics_by_Subject/index.php>.

USDA (2012a) *Agricultural Projections to 2021*. US Department of Agriculture.

USDA (2012b) *Livestock, Dairy, and Poultry Outlook*. US Department of Agriculture.

USDA (2012c) *Outlook for U.S. Agricultural Trade*. US Department of Agriculture.

USGCRP (2009) Global climate change impacts in the United States. In *United States Global Change Research Program*. (Eds TR Karl, JM Melillo and TC Peterson). New York.

Vergé XPC, Dyer JA, Desjardins RL, Worth D (2008) Greenhouse gas emissions from the Canadian beef industry. *Agricultural Systems* **98**(2), 126–134. doi:10.1016/j.agsy.2008.05.003.

Vinod A, McConnell KE, Umali-Deininger D, Haan CD (2003) Are the poor willing to pay for livestock services? Evidence from rural India. *Indian Journal of Agricultural Economics* **58**(1), 84–99.

Ward CE, Schroeder TC, Schulz L (2009) Impacts from government regulation on the Canadian–U.S. basis for fed cattle. In *Agricultural and Applied Economics Association 2009 AAEA/ACCI Joint Annual Meeting*, 26–29 July. Milwaukee, Wisconsin.

White TA, Snow VO, King WM (2010) Intensification of New Zealand beef farming systems. *Agricultural Systems* **103**, 21–35. doi:10.1016/j.agsy.2009.08.003.

Zjalic M, Dimitriadou A, Rosati A (2006) Beef production in the European Union and the CAP reform: an overview of situation and trends. *Stocarstvo* **60**(3), 181–202.

This page intentionally left blank

5 North American beef production

A.D. Herring

INTRODUCTION AND HISTORY OF BEEF CATTLE IN NORTH AMERICA

Cattle are not native to North America. Christopher Columbus brought cattle to the Caribbean islands in the 1490s not long after the discovery of the new world. As explorers then colonists came to various parts of North America, they brought cattle and other livestock from their native lands, primarily Great Britain and continental Europe, although some African cattle were also brought into the Caribbean islands. Although the broad interpretation of North America refers to Panama and the countries to its north, in this chapter most of examples, discussion and emphases strictly pertain to the countries of Canada, Mexico and the USA and there is more emphasis on US considerations, although a balanced treatment has been attempted where possible.

Cattle from Spain were brought into areas corresponding to present-day Mexico and Florida in the 1500s, whose descendants became Texas Longhorns (and related types such as Corriente) and Florida Crackers (Sponenberg and Olson 1992). British and Dutch cattle were brought into the New England area of the present-day USA in the 1600s. Cattle from France were brought into eastern Canada in the 1600s. These cattle were used for draft, milk and meat production and were therefore general, subsistence-type animals.

The first recognised modern breed brought to North America was the Durham (Shorthorn). Shorthorn cattle were imported into the USA in 1793 (ASA 2012) and into Canada in 1825 (CSA 2012), and are usually thought of as the first 'improved' breed to be brought to the new world; its US herd book was established in 1846. Hereford cattle were imported into the USA from England in 1817 (AHA 2012) and were first brought to Canada in 1860 (CHA 2012). The first Angus (Aberdeen Angus) cattle were imported into Canada in 1860 (CAA 2012) and into the USA in 1873 (AAA 2012). Ancestors of American Brahman cattle were imported into the southern USA from the late 1800s through the mid 1900s; these cattle were Asian Zebu (*Bos indicus*) in origin, but many came to the USA from Brazil (Sanders 1980). The first continental European beef breed to come to the USA was Charolais, by way of Mexico in the 1930s, and Charolais were brought into Canada from USA in 1955. Changes in vaccination and control strategies for foot and mouth disease in Europe led to an influx of many new cattle breeds from the UK and continental Europe in the late 1960s and early 1970s into Canada and the USA. Detailed information about these breeds in North America, as well as many others, is found at their respective breed association websites and through OSU (2012).

Cattle within biological groups (areas of origin) in Canada, Mexico and the USA have similarities in regard to characteristics such as body composition, milk production and heat/cold tolerance but there is substantial variation among and within breeds as well as among and within biological groups (Table 5.1). Generally, in North America, the British beef breeds are known for ability to deposit and retain body fat reserves, early age of puberty and desirable fertility and longevity. The continental European breeds are known for high degree of muscularity and lean body composition, but some are also known for high levels of milk production and are considered dual-purpose. The term 'American breeds' is used in the

Table 5.1: Breeds of cattle with presence (current or recent past) in Canada, Mexico and the USA

Breed name	Importance*	Origin	Biological group
Africander	Rare	South Africa	Sanga
Angus	Primary	Scotland	British beef
Ankole-Watusi	Rare–novelty	Zaire, Uganda	Sanga
Ayrshire	Small	Scotland	Dairy
Barzona	Minor	USA	1/4 Africander, 1/4 Hereford, 1/4 Angus, 1/4 Santa Gertrudis (5/32 Shorthorn, 3/32 Brahman)
Beefmaster	Primary	USA	*Bos indicus* composite (1/2 Brahman, 1/4 Hereford, 1/4 Shorthorn)
Belgian Blue	Minor	Belgium	Continental European beef
Belted Galloway	Minor	Scotland	British dual-purpose
Blonde d'Aquitaine	Minor	France	Continental European beef
Bonsmara	Minor	South Africa	Sanga-British composite
Boran	Rare	Ethiopia, Kenya	African *Bos indicus*, ebu
Brahman	Primary	USA	Zebu, developed from imported Asian Nellore, Gyr and Guzerat cattle
Braford	Small	USA	*Bos indicus* composite (5/8 Hereford, 3/8 Brahman)
Brangus	Primary	USA	*Bos indicus* composite (5/8 Angus, 3/8 Brahman)
Braunvieh	Major	Switzerland	Continental European dual-purpose
British White	Minor	England	British beef
Brown Swiss	Major	Switzerland	Dairy
Canadienne	Rare	Canada	Dairy, developed from imported French cattle
Charolais	Primary	France	Continental European beef
Chiangus	Major	USA	Continental–British composite (1/8 to 3/4 Chianina, 1/4 to 7/8 Angus)
Chianina	Small	Italy	Continental European beef
Corriente	Minor–novelty	Mexico	Criollo
Devon	Rare	England	British beef
Dexter	Rare	Ireland	British dual-purpose
Dutch Belted	Rare	Netherlands	Dairy
Galloway	Rare	Scotland	British beef
Gelbvieh	Primary	Germany	Continental European dual-purpose
Gir (Gyr)	Rare	India	Zebu
Guzerat	Rare	India	Zebu
Guernsey	Small	English Channel	Dairy
Hereford	Primary	England	British beef
Highland	Rare	Scotland	British beef
Holstein (Friesian)	Primary	Netherlands	Dairy
Indu-Brasil	Rare	Brazil	Zebu
Jersey	Primary	English Channel	Dairy
Limousin	Primary	France	Continental European beef
Maine-Anjou	Primary	France	Continental European dual-purpose
Marchigiana	Rare	Italy	Continental European beef
Mashona	Rare	Zimbabwe	Sanga
Milking Shorthorn	Small	England	Dairy
Murray Grey	Rare	Australia	British beef composite

Table 5.1: (*Continued*)

Breed name	Importance*	Origin	Biological group
Nellore	Minor	India	Zebu
Normande	Rare	France	Continental European dual-purpose
Parthenais	Rare	France	Continental European beef
Piedmontese	Minor	Italy	Continental European beef
Pinzgauer		Austria	Continental European dual-purpose
Red Brangus	Small	USA	*Bos indicus* composite (1/2 to 5/8 Red Angus, 3/8 to 1/2 Brahman)
Red Poll	Minor	England	British dual-purpose
Romagnola	Minor	Italy	Continental European beef
Romosinuano	Rare	Colombia	Criollo
Salers	Primary	France	Continental European dual-purpose
Santa Gertrudis	Primary	USA	*Bos indicus* composite (5/8 Shorthorn, 3/8 Brahman)
Senepol	Minor	Virgin Islands	Tropically adapted *Bos taurus*
Shorthorn	Primary	England	British beef
Simbrah	Major	USA	*Bos indicus* composite (5/8 Simmental, 3/8 Brahman)
Simmental	Primary	Switzerland	Continental European dual-purpose
South Devon	Small	England	British dual-purpose
Tarentaise	Small	France	Continental European dual-purpose
Texas Longhorn	Major–novelty	Texas and northern Mexico	Criollo
Tuli	Rare	Zimbabwe	Sanga
Wagyu	Minor	Japan	*Bos taurus* beef
WhitePark	Rare	England	British beef

* The classification used here (primary, major, small, minor, and rare) is based upon registrations, prevalence in overall industry and consideration of regional importance from most to least influential.

USA for Brahman and Brahman-influenced composites; they are known for maternal ability, longevity and heat and parasite tolerance. The Brahman breed was developed in Texas and Louisiana from imported Zebu (*Bos indicus*) cattle originally from Asia (India). Sanga represents the neck-humped cattle native to Africa. Criollo cattle originate from Spain and Portugal. Dairy refers to breeds that are extremely high in milk production.

This list in Table 5.1 is not exhaustive of all 'breeds' in North America, but it includes the recognised breeds that impact beef production either directly or indirectly or have been evaluated for research purposes due to perceived production potential. Several breeds in the rare category may have been introduced by individuals or through research institutions and may or may not have active breed associations. There are many localised types of cattle that some may consider as breeds because they have shared ancestry and are unique and closed populations (e.g. Florida Cracker cattle, populations of local Criollo in northern Mexico etc.), but these are not considered in this listing.

There are many local populations of cattle within North America that may not be officially recognised as breeds but that represent unique genetic resources. The American Livestock Breeds Conservancy was formed in 1976 in an attempt to describe and support rare and potentially endangered breeds of livestock. Rare Breeds Canada was formed in 1987 with a similar goal. The USDA has established a formal genetic conservation program (National Animal Germplasm Program, NAGP 2012) to catalogue and store semen and embryos of all livestock breeds in USA. It should be of concern for the diversity of the livestock gene pool in North America that these localised populations of cattle (and other livestock species) are generally viewed as 'replaceable' because other breeds have higher production capabilities.

Beef cattle production historically and presently is very important to national and local economies throughout North America, with different degrees of influence across diverse regions (Table 5.2). Collectively, North American countries are responsible for ~24% of the world's beef exports and ~27% of global beef production (Chapter 4).

Table 5.2: Summary of beef production, consumption and international trade for North American countries for the market year 2010*

Country/region	Beef and veal production	Domestic consumption	Beef exports	Beef imports	Per capita beef consumption (kg)
Canada	1272	999	523	243	30
Costa Rica	95	77	23	5	17
Dominican Republic	46	51	0	5	5
El Salvador	22	50	0	28	8
Guatemala	77	77	9	9	6
Honduras	27	27	3	3	3
Jamaica	6	14	0	8	5
Mexico	1751	1944	103	296	17
Nicaragua	137	19	118	0	3
USA	12 047	12 039	1043	1042	39
Total of North America	15 480	15 297	1822	1639	–
World	57 043	56 243	7702	6901	–
North American share of world market	27.1%	27.2%	23.7%	23.8%	–

* Metric tonnes (in thousands) except for per capita consumption; all expressed on carcass weight equivalent basis (bone-in weight). Data from USDA Foreign Agricultural Service (FAS 2012).

INDUSTRY STRUCTURE AND INFRASTRUCTURE

Land area, population and some agricultural production statistics for North American countries and global totals are provided in Table 5.3. Agricultural lands in Canada, Mexico and the USA are ~672 000, 1 026 000 and 4 035 000 km^2, respectively. All three countries produce a wide variety of agricultural crops and livestock. The percentage of these nations' gross domestic product (GDP) directly due to agriculture and associated raw (directly off farm) products is only 1–4%, which partly explains why many people might take agriculture for granted. It is expected in more developed nations that agriculture will constitute only a small percentage of GDP, not because total value declines but because its relative value compared to other industries declines. Consideration of the associated allied industries and value-added components likely accounts for a much greater share of GDP across North America.

Table 5.3: General descriptive comparisons of North American countries with the world for select land area, human population and productivity categories in 2010

Category	Canada	Mexico	USA	World
Land area (million km^2)	9.09	1.94	9.15	129.71
Total population (million)	34.1	113.4	309.1	6840
Agricultural land as % of land area	7.4	52.9	44.1	37.7
% of population in rural area	19	22	18	49
Population density (people/km^2)	3.8	58.4	33.8	52.8
GDP (US$ trillion)	1.34	0.87	14.12	58.09
% of GDP from agriculture and value-added components	2	4	1	3.2
Land under cereal grain production (million ha)	14.9	9.1	58.0	699.18
Average cereal grain yield (t/ha)	3.3	3.1	7.2	3.5
Livestock production index (1999–2000 = base of 100)	105	123	108	130
Land in permanent meadows and pasture (million ha)	15	75	238	3356

The livestock production index includes meat and milk from all sources, dairy products, eggs, honey, raw silk, wool, and hides and skins.
Source: Adapted from data from World Bank (2012) and FAOSTAT (2012).

The segments of North American beef production are typically referred to as cow–calf, stocker, feedlot (or feeder), packer, purveyor and consumer. These segments and some industry infrastructure are individually defined and discussed below.

Cow–calf operations

Any operation that maintains beef cows for breeding purposes and produces calves is referred to as a cow–calf operation. The cow–calf sector is the traditional ranching portion of the North American cattle industry. There is large variation in size of operations across and within geographical regions. The cow–calf segment is dominated by many smaller operations (Fig. 5.1), with an average beef herd size of ~41 cows in the USA and ~61 in Canada. In Mexico, very small operations are even more common, with more than 1.2 million cattle found in herds of fewer than five animals (Peel *et al.* 2010).

This segment is further divided into seedstock and commercial components. Seedstock operations are typically purebred operations, but have the primary purpose of selling breeding animals, most notably bulls. These producers commonly register their animals with a breed association (breed society) and record detailed pedigree and performance information on their cattle. Commercial cow–calf operations are those that produce non-registered animals and supply most of cattle for beef production. It is quite common that seedstock operations also have a commercial (i.e. non-registered or non-purebred) component. Commercial operations commonly purchase purebred, registered bulls with documented performance from seedstock operations and rely on use of crossbred cows. Commercial operations are far more common that purebred operations throughout North America (Table 5.4).

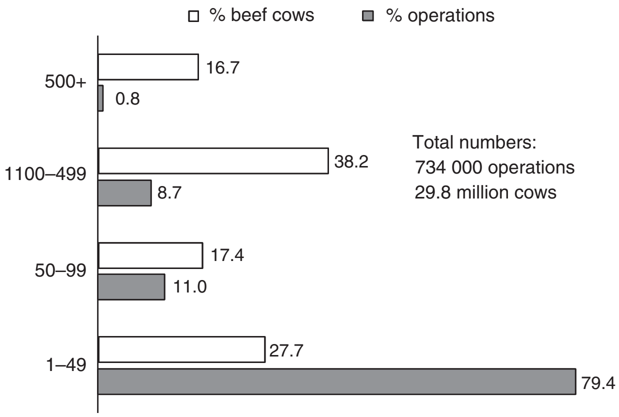


Figure 5.1: Distribution of 2011 USA beef cow and operation percentages according to herd size (e.g. herds with <50 cows make up 79.4% of beef cow operations and have 27.7% of the beef cow inventory). Source: Data from USDA NASS (2012).

Table 5.4: Percentage of operations in the USA according to best description of breeding cow herd type

	Herd size category (no. of breeding cows)				
Description	**1–49**	**50–99**	**100–199**	**200+**	**Overall**
Seedstock	11.1	6.0	4.9	4.8	9.5
Commercial	76.3	74.2	79.8	77.7	76.3
Both	12.6	19.8	15.3	17.5	14.2
Total	100.0	100.0	100.0	100.0	100.0

Source: USDA NAHMS (2009).

Stocker operations

The terms ‘stocker calves’ or more commonly ‘feeder calves’ refer to young cattle (6–10 months of age; 200–400 kg liveweight) that are placed into grazing (therefore forage-based) scenarios for a brief period (typically three to six months) to gain weight before being placed into a feedlot. Young, growing cattle are efficient at weight gain from high-quality forages (Chapter 18). In most scenarios, the cost of weight gain in stocker programs is lower than in confined feeding programs (although the rate of gain is typically higher in confined feeding). Cost of gain is simply the total dollars required per unit of weight gain. The advantage of stocker programs for reduced cost of weight gain becomes larger when feed grains become more expensive. Many stocker operations rely on improved forage crops such as small grains (e.g. wheat, oats, rye, triticale) or cool season forages such as grasses and/or legumes during the autumn and winter months (October–March) or warm season forages during the spring and summer months (April–September). Stocker operations are found throughout North America, but have their heaviest concentrations in the US southern Great Plains. For stocker cattle on high-quality forage, typical weight gain is 0.7–1.1 kg/day (1.5–2.5 lb/day), and typical cost of gain on high-quality forage is $0.85–1.45 per kg (2012 prices in US$).

A major health consideration for stocker operations (and for feedlots) is bovine respiratory disease (BRD) complex, which historically was called ‘shipping fever’. There are four viral BRD pathogens, each of which can cause their own disease: infectious bovine rhinotreachitis (IBR), bovine respiratory syncytial virus (BRSV), bovine viral diarrhoea (BVD) and parainfluenza-3 (PI3). These viral diseases individually or in combination make animals susceptible to secondary bacterial infections that can lead to pneumonia (Powell 2009; Chapter 13). Health issues associated with BRD are major factors in determining profit for stocker and feedlot operators.

Cattle feeding industry

The US cattle feeding industry was developed through feeding of cheap grains, primarily corn but, depending upon the region and year, sorghum and barley have also been used extensively as energy sources in feedlot diets. Historically, the US corn crop has been predominantly grown for livestock feeds. Many people falsely believe that there is a choice between feeding corn and other grains to people and feeding it to livestock. This is a false belief because entirely different crop varieties are used for food-grade *v.* livestock feed grain. In the USA, a government-mandated emphasis (Hoffman and Baker 2011) on corn-based ethanol production has dramatically increased the price and the utility of corn for livestock feeding. This has had a trickle-down effect, increasing the price of many domestically produced foods including all meats and their products, and livestock prices across the food animal industries. From 1995 until 2005 typical feedlot finishing cost (US$) of gain was $1.10–1.75 per kg for steers and heifers, but since 2008 it has fluctuated between $2.00 and $2.70 per kg.

Small-scale cattle feeding of grain and feed by-products has existed in many areas of the world for several hundred years and in grain-producing areas of the USA since the cattle-drive days of the late 1800s (Ball 1992). The modern large-scale US cattle feeding industry began in the 1960s when larger, specialised cattle feeding operations began to appear in the Great Plains region (Fig. 5.2). A typical feedlot today has a capacity of 30 000–50 000 animals (although much wider ranges exist) and will have 2–2.25 'turns' of cattle per year, meaning it will receive and ship out 2–2.25 times its capacity annually (MacDonald and McBride 2009).

In recent years, some feedlots have specialised in receiving groups of lightweight calves from livestock auctions as other feedlots have transitioned to more emphasis on heavier cattle with less feeding time; lightweight calves are typically animals that have been commingled (coming from various origins, not raised together as a cohort group) and are freshly weaned calves with unknown background information on health and vaccination status. These are thought of as 'high-risk' calves because they have been under substantial stresses of weaning, commingling and long-distance transport. If these types of calves have not been properly vaccinated against likely pathogens, they have a much higher probability of becoming ill, and have increased risk of mortality. Feedlots that specialise in 'straightening out' cattle like this are referred to as backgrounding yards or feedlots, as opposed to finishing yards or feedlots. Many feedlots receive and manage all types of cattle, and may

Figure 5.2: A large-scale North American feedlot. Cattle are housed in dirt-floor pens that hold 50–200 animals and are fed grain-based diets three times per day, by truck, in concrete feed bunks. Feedlots have their own feed mills (seen in background) and formulate and mix their own rations. Source: A.D. Herring.

feed cattle that are owned by another entity (custom-fed cattle) or that have been purchased by the feedlot (company-owned cattle).

A typical cattle feeding regimen begins with a starter ration that is 40–45% grain and has substantial roughage (Chapters 11, 16). This may be fed for a few days to a few weeks. Cattle are then incrementally transitioned through a series of rations where the amount of grain is increased and the amount of roughage is decreased. The intermediate rations are referred to as grower rations (50–65% grain) and the ration at the end of the feeding trial is referred to as a finisher ration (70–85% grain). Depending upon the size and age of the cattle, the grower portion of the diet may be consumed for a few weeks, and the finisher portion is likely to be fed for two to six months. Corn has been the primary grain used in US cattle feeding, barley has been commonly used in Canada and sorghum grain has historically been used in Mexico. All grains may be used in all areas depending upon relative prices and availability.

Cattle feeding capacity in Canada is ~1.7 million animals, and in the USA is ~12.5 million. In 2010 there were 3.3 million cattle fed in Canada (CANFAX 2011) and 22 million cattle fed in the USA (USDA NASS 2011b). Grain finishing has been much less common in Mexico, but changes in consumer preferences have resulted in growth in the cattle feeding industry in Mexico typically in the form of confined and semi-intensive finishing programs with concentrate feeding (Peel *et al.* 2011). Many areas have also imported distillers' grain, as more corn in the USA has been used for ethanol production (Peel *et al.* 2011).

Beef packing industry

The beef packing industry transforms live animals into meat products and by-products. Historically, beef carcasses have been split down the centre of the vertebrae to produce two sides of beef. Then, since carcasses are 'ribbed' for grading between the 12th and 13th ribs, this produces two beef carcass quarters (forequarter and hindquarter) from each side. Romans *et al.* (2001) provided detailed discussion of all US meat industries. Prior to 1966, most beef was shipped in forequarters and hindquarters from packing plants to processing facilities or retail outlets, but since the mid 1970s most beef shipped to grocery stores has been prefabricated, already processed into specific cuts (Romans *et al.* 2001). This trend has accelerated since the 1980s; currently, most US and Canadian beef is shipped as 'boxed beef' (i.e. boxes of specific beef cuts). As a result, modern large-scale beef plants also perform complete carcass fabrication (historically done at a butcher shop or in the butcher section of a grocery store). This also means that there is not much of a separate beef processing industry segment in most of North America. There was considerable consolidation among the beef packing industry between the 1970s and 2000s (as was also the case in other food animal industries) as larger organisations can better capitalise on efficiencies of scale.

The largest beef packing plants will process 4000–6000 cattle per day, operating in two 8 h shifts. Carcasses are moved by series of overhead rails and conveyor systems and operate in a manufacturing/assembly plant format where the animals, carcasses and products are brought to the people at their work stations (Chapter 2). Typically beef is graded and fabricated (broken into various cuts) two days after harvest, and leaves the packing plant as boxed beef in refrigerated trucks. It is taken to distribution centres and from there goes to retail outlets of grocery stores and food service. It is typical that from the time of harvest to retail is 10–14 days but the range can be greater, especially if a grocery store is moving a lot of (or little) product through special sales. The number of beef (and all livestock in general) processing plants over time has continued to decrease as firms consolidate. MacDonald *et al.* (1999) reported that the share of US shipments from large cattle packing plants went from ~30% in the late 1960s and early 1970s to 72% in 1992, and that 16% of cattle were slaughtered in plants processing over 500 000 animals annually in the 1960s–70s, but this had increased to 80% by 1997. Various reports from the US Census Bureau (2012) show that the number of US beef packing plants decreased dramatically in the 20 years from 1982 to 2002 from almost 400 to 180, but this number has decreased much more slowly since 2002.

Regional distribution of cattle

Beef cows in North America are found in areas that are not suitable for row crop production to utilise native and/or improved forages, and in areas where row crop farming is common to utilise crop residues. There is wide diversity in distribution of cows (cow–calf sector), stocker operations and feedlots. Breeder cows are found where forages are prevalent, while stocker operations commonly locate where small grains or nutritionally desirable grass are grown (Table 5.5). Feedlots are usually located where grain and desirable climatic conditions exist. Beef packing plants that were historically located near major stockyards moved to be close to feedlot areas. Distributions of beef cows are shown in maps of these countries in Figs 5.3 to 5.5.

Table 5.5: Leading provinces and states for beef cows (animal numbers 1000) in Canada, Mexico and the USA

Rank	Canada	Mexico	USA
1	Alberta (1660)	Chihuahua (363)	Texas (4365)
2	Saskatchewan (1294)	Sonora (290)	Nebraska (1884)
3	Manitoba (498)	Tamaulipas (244)	Missouri (1857)
4	Ontario (316)	Jalisco (242)	Oklahoma (1728)
5	Quebec (213)	Nuevo Leon (224)	South Dakota (1610)
6	British Columbia (195)	Coahuila (221)	Montana (1456)
7	Nova Scotia (21)	Veracruz (205)	Kansas (1427)
8	New Brunswick (19)	Durango (188)	Kentucky (995)
9	Prince Edward Island (12)	Tabasco (140)	Tennessee (950)
10	Newfoundland & Labrador (<1)	Sinaloa (119)	Florida (940)
Total	4228	3239	29 883

Sources: CANFAX (2011); USDA NASS (2011b); Peel *et al.* (2010).

In the USA and Canada, a large number of cattle are concentrated in the Great Plains area in the central part of the continent due to the abundance of small grains (e.g. wheat, oats, barley, rye), corn and sorghum as well as substantial areas of improved and native grasses. In many areas soybeans are also commonly grown, and to the south cotton is common. Both soybean meal and cottonseed meal are common protein components in cattle feeds in North America. Consequently, there are many cows, stocker operations, feedlots and packing plants in the middle region of the North American continent. The areas of Canada, Mexico and the USA with the highest total cattle numbers are provided in Table 5.6. The differences between Tables 5.5 and 5.6 is that Table 5.6 includes cattle in any or combinations of feedlots, dairies, ranches, growers etc. whereas Table 5.5 emphasises the ranches and farms where beef breeding cows are located.

Animal transport

The North American cattle industry (and many others) relies on transportation by truck (Fig. 5.6). Trucks in the USA commonly carry loads of up to 22 680 kg (50 000 lb) or slightly less. Cattle are not shipped by train (as was commonly done until the 1950s). Shortly after weaning, many calves are transported to areas where they are grown out on forage (in stocker operations) or transported directly to a feedlot, which may be several hundred to well over 1000 km from the calves' point of origin. Cattle leaving a stocker operation are also transported by truck to a feedlot, which again may be nearby or several hundred kilometres away; cattle are transported from feedlots to packing plants that are usually 200 km or less (many feedlots are located less than 100 km from a packing plant). After harvest and fabrication, beef is transported by refrigerated truck to distributors and then to food service and grocery store outlets.

Food safety

Grading of beef is primarily done for marketing purposes (Chapter 2). Inspection of beef is done to protect consumers by ensuring its safety, wholesomeness and correct labelling and packaging. Beef inspection in the USA is conducted through the Food Safety Inspection Service (FSIS) and administered through the USDA, which is headed by the US Secretary of Agriculture. In Canada, the Canadian Food Inspection Agency (CFIA) is responsible for beef inspection and safety, administered through Agriculture and Agri-Food Canada, which is headed by the Canadian Minister of Agriculture and Agri-Food. In Mexico, beef inspection is accomplished through the National Service of Health, Food Safety and Food Quality (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria, SENASICA), which is administered through the department headed by the federal agricultural secretary (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, SAGARPA).

Animal identification

Canada has the most comprehensive national animal identification (ID) system in North America. The Canadian Cattle Identification Agency (CCIA 2012) has been in existence since 2001 and is enforced by the CFIA. Approved ear tags, visually and electronically embedded with a unique identification number, are applied to all cattle before they leave the ranch or farm of origin; tags are distributed to producers through authorised dealers. The unique number of the animal is maintained to the point of export or carcass inspection where the animal is either approved for consumption or condemned. Mexico began a national animal ID program (SINIIGA 2012) in 2003, enforced through the office of the federal agricultural secretary (SAGARPA). Many states in Mexico have their own animal ID systems and the federal system has

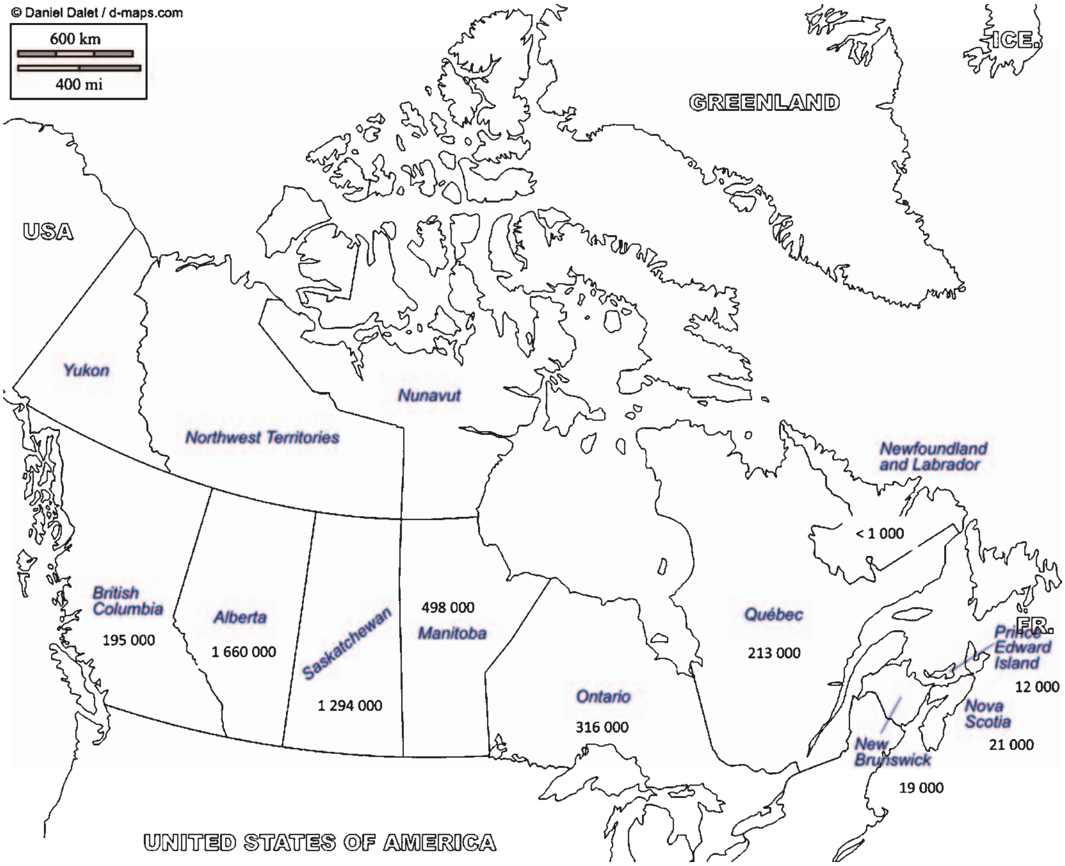


Figure 5.3: Canadian beef cow inventory for provinces with beef cows on 1 January 2012. Total Canadian beef cow inventory = 4.228 million. Source: Data from CANFAX (2011); map template from d-maps.com.

been reported to be not as useful as needed for tracking animals, and does not involve animal health officials (Ortega and Peel 2010). Several western US states have branding laws to provide proof of ownership of cattle, but do not require individual animal ID. As of 2012 the USA did not have a national animal ID system, although it has been the subject of debate since the late 1990s; many US producers and industry groups are voluntarily documenting and providing traceability information and are being financially rewarded through alliance marketing programs targeting consumers that desire this type of information (IMI Global 2012).

Industry infrastructure assessment

Since 1840, a national agricultural census has been conducted regularly in the USA (USAC 2012), at 10-year intervals until 1920 and at about five-year intervals since. An agricultural census was initiated in some provinces in Canada in 1896, and a national agricultural census in five-year increments began in 1956 with the 2011 information recently summarised (Statistics Canada 2012). Detailed information about many beef (and other agricultural) industry components in the USA and Canada can be found at their agricultural census websites.

BREEDS, GENETIC RESOURCES AND GENOTYPE BY ENVIRONMENT INTERACTIONS

Within Canada, Mexico, and the USA there are widely varying geographical and environmental conditions, but there are also similarities where political boundaries are the only distinction (see below). Within the USA, environmental conditions range from humid and subtropical in the Gulf Coast region, to semi-arid and arid in the south-west states. Across the continent there is wide variation in annual precipitation, generally decreasing from east to west and across mountain ranges. The northern US and southern Canadian regions have 90–130 frost-free days per year, whereas portions of California, Texas,

Figure 5.4: States of Mexico with numbers of beef cows in top 10 states. Source: Data from Peel *et al.* (2010); map template from d-maps.com.

Florida and much of Mexico rarely experience frost (USDA ARS 2012). There are geographical similarities across countries in the Pacific North-west in Washington and British Columbia, in the plains states of Montana and the Dakotas and Alberta and in the US states of Arizona, New Mexico and south-west Texas with the northern Mexican states of Sonora, Chihuahua and Coahuila. Numerous other similar comparisons could be made. In all instances, cattle producers are best served when they utilise cattle types suitable to local conditions. This statement is paramount for cow–calf producers as beef cows are prevalent throughout all parts of North America except for extreme northern regions of Canada and in Alaska, and wide variation in production environments calls for wide variation in types of cattle adapted to those conditions.

The major biological groups of domesticated cattle are found in North America, and much of the North American beef production, particularly in the USA and Canada, is based on British breeds and crosses. In much of the Gulf Coast and southern USA, *Bos indicus*-influenced (American) breeds and their crosses are prevalent. There are also straight *Bos indicus* cattle (almost exclusively of the Brahman breed) in the USA but they are much less common than their crosses with *Bos taurus* breeds. In Mexico, higher percentage *Bos indicus* and Criollo cattle are more common, and there are more crosses among these types. Almost all the breeds found in the USA are also found in Canada and Mexico, and obviously there is less overlap of breeds between Canada and Mexico than between either of these countries and the USA. In Canada and the USA there is more emphasis on cattle that are specialised for beef and dairy production, but in Mexico there is more dual-purpose utilisation of cattle. Every year hundreds of thousands of Mexican cattle are fed in Texas, New Mexico and Arizona feedlots; these cattle may also go to feedlots further north such as in Colorado, Kansas and Nebraska.

The percentage of the 2007 calf crop classified according to biological group on US beef cattle operations (Table 5.7) indicates that most calves were classified as entirely British (39.8%), compared to entirely continental European (11.6%) or entirely *Bos indicus* influenced (7%). From this survey, 77% of operations reported having at

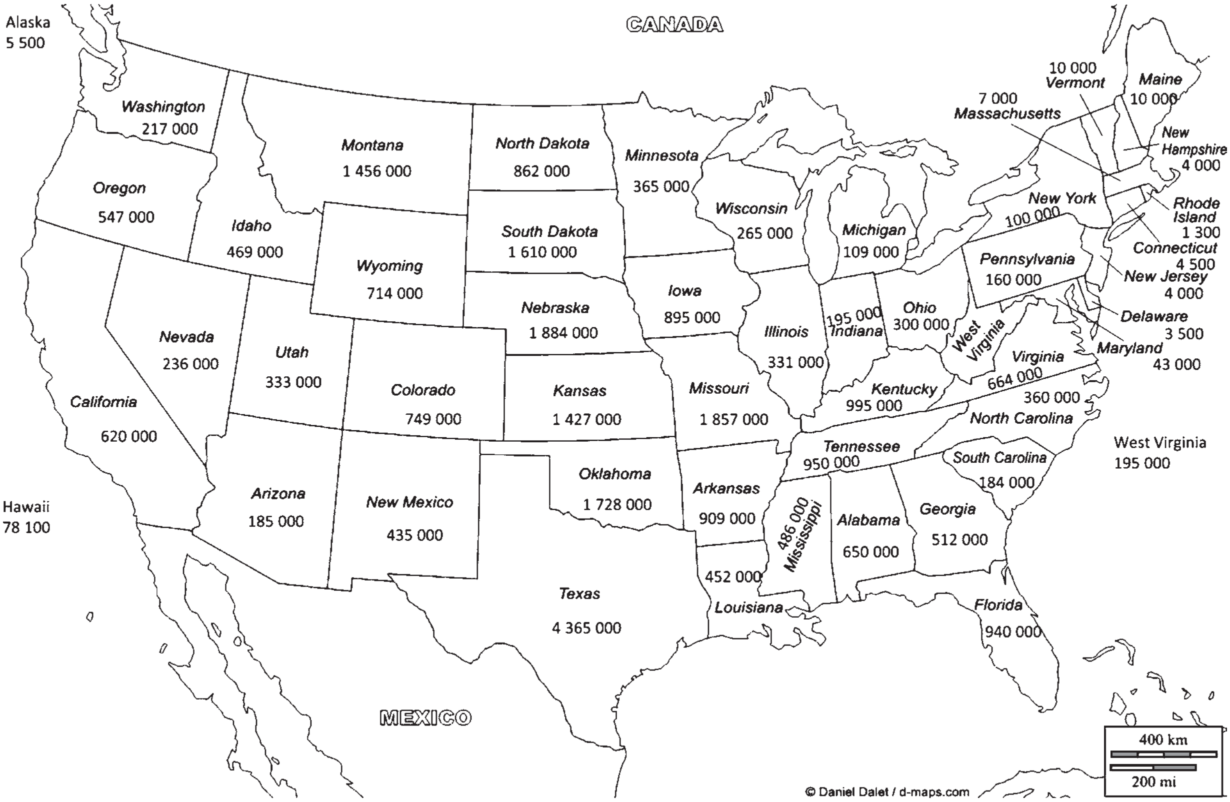


Figure 5.5: Beef cow inventory for each state on 1 January 2012. Total US beef cow inventory = 29.883 million. Source: Data from USDA NASS (2012); map template from d-maps.com.

least some British influence, 44% reported at least some Continental influence and 20.2% reported at least some *Bos indicus* influence in their calves.

Use of breed (and family) resources is a powerful genetic tool for matching animals with environmental conditions as well as producing cattle tailored to specific markets (Table 5.1). No single breed has the ideal combination of calf growth and size, post-weaning growth and carcass performance, and female reproduction and productivity. There is also considerable variability within breeds. Choice of breed and individual animal types should be the first level of priority in a breeding program, and how to combine these resources for optimal efficiency and sustainability, e.g. through crossbreeding systems, should be the next consideration (Chapter 17).

The major breed associations have breed improvement programs for producers to collect and record performance traits, and in return provide estimates of genetic merit (EPDs = expected progeny differences, rather than EBVs = estimated breeding values (Chapter 18) where 0.5 * EBV = EPD). Genetic evaluation and resulting EPDs for growth and size traits have existed since the 1970s for many breed associations, but in the 1990s and 2000s additional emphasis was placed on carcass traits and reproductive

Table 5.6: Leading provinces and states for total cattle (animal numbers 1000) in Canada, Mexico and the USA

Rank	Canada	Mexico	USA
1	Alberta (4995)	Veracruz (2454)	Texas (11 900)
2	Saskatchewan (2600)	Jalisco (1932)	Nebraska (6450)
3	Ontario (1714)	Chihuahua (1709)	Kansas (6100)
4	Quebec (1260)	Chiapas (1406)	California (5350)
5	Manitoba (1165)	Sonora (1352)	Oklahoma (4500)
6	British Columbia (540)	Durango (1233)	Missouri (3900)
7	Nova Scotia (85)	Tamaulipas (1055)	Iowa (3900)
8	New Brunswick (79)	Michoacan (1005)	South Dakota (3650)
9	Prince Edward Island (65)	Sinaloa (965)	Wisconsin (3400)
10	Newfoundland & Labrador (11)	Tabasco (958)	Colorado (2750)
Total	12 515	23 317	90 769

Source: CANFAX (2011); USDA NASS (2011b); Peel *et al.* (2010).

Figure 5.6: Typical North American cattle truck. Source: A.D. Herring.

Table 5.7: Percentage of US operations by proportion of 2007 calf crop designated by cattle biological group

Biological group	Relative proportion of calf crop attributed to biological group					
	All	Most	Half	Some	None	Total
British	39.8	15.1	13.6	8.5	23.0	100.0
Continental	11.6	6.3	11.0	15.1	56.0	100.0
Bos indicus influenced	7.0	3.1	3.0	7.1	79.8	100.0

Designations of 'All', 'Most' etc. refer to the relative proportions of the calf crop of that were classified as biological groups. Numbers refer to the percentages of operations that classified their calf crops for a particular biological group (39.8% said their calves were all British, 15.1% stated their calf crop was mostly British, 13.6% said their calf crop was half British etc.). In the categories 'Most' and 'Some', responses could represent values of 50–100% and 0–50%, respectively, based on producer information or perception.
Source: USDA NAHMS (2009).

Table 5.8: Registrations of new animals for select US breed associations, 2012

Breed	Number	Breed	Number
Angus	282 911	Charolais	57 199
Hereford	64 907	Simmental	49 000
Shorthorn	14 653	Limousin	23 716
Red Angus	46 094	Gelbvieh	34 963
Holstein	339 908	Chianina	6374
Jersey	90 366	Maine Anjou	8359
Milking Shorthorn	2796	Salers	5536
Guernsey	4844	Brahman	9300
Ayrshire	4131	Brangus	24 843
Brown Swiss	10 658	Beefmaster	16 000
Texas Longhorn	8400	Santa Gertrudis	5000

Source: Adapted from National Pedigreed Livestock Council (2012).

performance. Most commercial producers purchase registered purebred bulls from seedstock operations as the source of genetic improvement in their herds. Registrations of new animals into the herd books of several breed associations in the USA (2010 or 2011) varied from a few thousand to hundreds of thousands of animals (Table 5.8).

There are a variety of reasons why breeds increase, sustain or decrease in popularity over time. Shorthorn was the main beef breed in the USA until ~1900, but its popularity began to decline after more Shorthorn than Hereford cattle died in extreme winters in the late 1880s. In the early 20th century through to the 1980s, Hereford was the predominant breed. The Certified Angus Beef program was launched in 1978, increasing the popularity of Angus, which has been the predominant breed since the early 1990s. In 1965, US Angus registrations were ~385 000 and US Hereford (horned and polled associations) registrations were ~623 000. In 1965, Charolais was the only continental European breed with a US registry (31 000 registrations). Also in 1965, US registrations for Brahman, Brangus and Santa Gertrudis were ~16 000, 12 000 and 4000, respectively.

Commercial cow–calf producers should utilise crossbred cows for increased reproductive performance and calf survival no matter what their geographical location or target market, but their choice of breeds and animal types should vary accordingly to specific local conditions (Chapter 17). Producers that do not utilise crossbreeding are sacrificing performance potential, and there is no reason not to crossbreed for commercial beef production unless premiums with specialised marketing programs outweigh the reduced performance per cow expected with purebreds. Cattle producers value crossbred animals for perceived productivity, as indicated from the description of US beef cow herds in regard to breeding system type (Table 5.9). Overall, 17.5% of the herds identified as having purebred cows (conversely, 82.5% were not purebred) and crossbreeding systems involving two breeds were the most common across all herd sizes.

MARKETING CHANNELS AND GRADING STANDARDS

The most common method of determining value of commercial cattle has been visual appearance and liveweight. Liveweights are commonly determined through use of animal scales at auctions or weighing trucks loaded and then unloaded at point of delivery. This is the basis of value determination of cattle and their subsequent products being sold from one producer to another, as well as sales of animals from one industry sector to another (cow–calf to stocker or feedlot, feedlot to packer, packer to food industry etc.). The most common method of determining value of cattle leaving ranches in Canada and the USA is through livestock auctions. Throughout North America, cattle marketing practices vary widely across regions. In Canada and the USA there are industry livestock marketing associations as well as public reporting of prices and federal government oversight of reporting. Peel *et al.* (2010) reported that in Mexico marketing institutions for live cattle are minimal and there is little public reporting of stocker and feeder cattle prices because transactions occur primarily through direct sales (which might also go through an intermediary). Canada, Mexico and the USA each have a national system for reporting prices of slaughter cattle and beef carcass prices.

Table 5.9: Percentage of US beef operations according to their best description of genetic type of cow across herd sizes

	Herd size (no. of cows)				
Genetic type	**1–49**	**50–99**	**100–199**	**200+**	**Overall**
Purebred	16.1	20.9	18.3	23.9	17.5
Composite	14.3	13.3	7.2	8.5	13.3
Crossbred (2 breed)	42.9	47.4	54.5	51.3	44.9
Crossbred (3+ breed)	26.7	18.4	20.0	16.3	24.3
Total	100.0	100.0	100.0	100.0	100.0

Source: USDA NAHMS (2009).

Marketing opportunities vary across industry sectors. The majority of cattle from ranches and farms are sold through auctions (public sales), however, the majority of cattle sold by feedlots to packers is accomplished directly (private sales). Also, the method utilised in public and private sales varies considerably. For instance, cattle producers can utilise existing auction markets, or hold an auction on their own (physically or through the internet) or in combination with other producers (through a cooperative effort). Feedlot cattle may be sold privately on a liveweight basis, on a carcass weight basis that is driven by dressing percentage, or on a carcass-based grid where quality grade, yield grade and carcass weight dictate price. In general, there has been an increase in opportunities for producers to market their animals, and producers that utilise more specialised marketing (as opposed to straight commodity considerations) can receive value-added pricing (CattleFax 2012).

Herd size is related to geographical region, with smaller operations typically selling weaned calves through generic (non-specialised) cattle auctions. Most of these occur weekly in much of Canada and the USA. Auctions provide a convenient and expedient way of marketing animals (Table 5.10) but producers that market animals this way have less control of price and merchandising opportunities. Many beef producers have learned that utilising value-added aspects of marketing can enhance prices considerably. The types of entities animals are sold to when leaving their farm or ranch of origin are shown in Fig. 5.7.

Concentration and marketing arrangements considerations

In low profit margin businesses, it is typical that some operations will grow in size over time to capture

Table 5.10: Percentage of US beef cow operations that marketed cattle through various programs

	Herd size (no. of breeding cows)				
Program	**1–49**	**50–99**	**100–199**	**200+**	**Overall**
Breed-influenced	11.7	15.9	16.1	28.6	13.6
Age and source verified	5.2	11.7	14.9	29.0	8.2
Conventional	60.5	68.7	68.4	67.8	62.8
Natural	28.8	25.3	24.4	30.8	28.0
Certified organic	1.2	0.2	0.3	1.3	1.0
Other	1.4	0.8	2.6	2.3	1.5

Source: USDA NAHMS (2008).

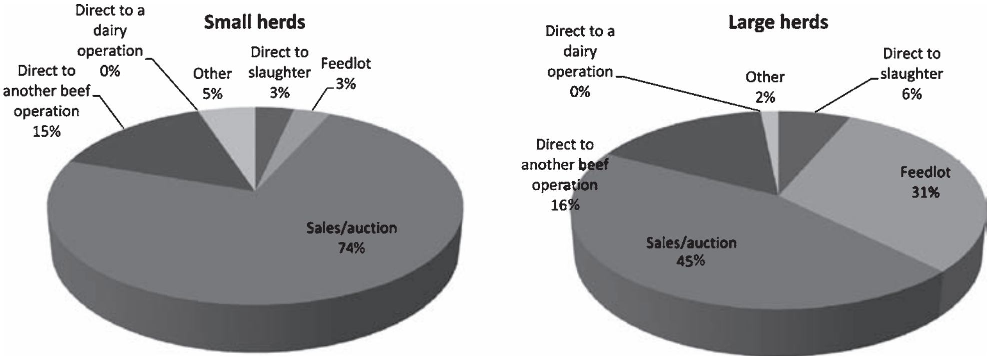


Figure 5.7: Percentage of cattle that permanently left US beef cow operations as marketed through different channels for small herds (<50 cows) versus large herds (200+ cows). Source: USDA NAHMS (2009).

economies of scale and increase overall profit by increasing turnover. This happens throughout the North American livestock industries. However, when there are few entities within a particular sector (e.g. to bid on cattle), this scenario makes sellers sceptical about competitive transactions and receiving fair market prices. When producers have the potential to market their animals/products to a variety of potential buyers and through a variety of marketing avenues, this is a fairer situation that is likely to be more sustainable.

Concentration and creation of unfair marketing arrangements and prices has been a concern for some US livestock producers since the late 1800s. The Packers and Stockyards Act of 1921 led to the creation of the Packer and Stockyards Program (currently a component of the USDA Grain Inspection, Packers and Stockyards Administration, GIPSA) which is charged with oversight of financial transactions of US meat animal industries. Its stated mission is 'To protect fair trade practices, financial integrity, and competitive markets for livestock, meat, and poultry.'

In 1980, ~36% of fed cattle were processed by the four largest beef packers in the US industry, but this percentage had increased to 81% by 1995 and to 85% by 2010 (data from various GIPSA reports). Concentration in cow and bull (non-fed) slaughter processors has always been less than for fed-cattle slaughter, but the same trends exist and have been growing. From 2000 to 2007 non-fed cow and bull slaughter accounted by the four largest firms increased from 31% to 55% and seems to have plateaued at least to 2010 (GIPSA 2012).

There is more consolidation within the cattle feeding industry as well. MacDonald and McBride (2009) evaluated the US cattle feeding industry and reported that, in 2007, 262 feedlots had a capacity of at least 16 000 animals and were responsible for 60% of US fed-cattle marketing. In the mid 1970s, ~19% of feedlot cattle were from feedlots over 32 000-animal capacity and 36% were from feedlots under 1000 animals; however, by 2004 ~43% and 14% of cattle were from feedlots over 32 000 and under 1000, respectively (MacDonald and McBride 2009). The consolidation trend also occurs at the cow–calf level but is less apparent due to a larger number of operations.

Feeder cattle grades and value

The US Department of Agriculture (USDA AMS 2000) has standards for evaluation of feeder cattle, and these descriptors are also commonly used in Mexico and Canada. Feeder calf grades are based on frame size, muscle score and health status (referred to as thriftiness) in young cattle (6–12 months old). Feeder calf frame size grades are Small, Medium and Large, and estimate the weights at which cattle are expected to have 12–13 mm (0.5 inch) of fat cover over the last two (12th and 13th) ribs after an intensive feeding period of five to eight months. The empty (i.e. weight before eating or being fed) liveweights of Small, Medium and Large frame heifers are expected to be <454 kg (1000 lb), 454–522 kg (1000–1150 lb) and over 522 kg (1150 lb), respectively. Small, Medium and Large frame steers are expected to be <499 kg (1100 lb), 499–567 kg (1100–1250 lb) and >567 kg (1250 lb), respectively. Cattle buyers prefer Medium and Large frame feeder calves and there is usually no price distinction between these two frame grades, but Small frame feeder calves typically receive a substantially lower price (US$0.33–0.56 per kg, US$0.15–0.25 per lb). Cattle buyers also prefer more heavily muscled calves, and prices typically show more of a gradient across muscle scores. Feeder calf muscle scores are No. 1, No. 2, No. 3 and No. 4, which proceed from very muscular (No. 1) to very little muscle expression (No. 4) with prices following the pattern from

Table 5.11: Visual descriptions, associated frequencies and liveweight prices of feeder calves in Arkansas auctions in 2010

Trait	Category	Frequency (%) within trait	Price (US$ per kg)	Price deviation from average (US$ per kg)
Muscle score	1	78.5	2.44	0.05
	2	20.1	2.24	–0.15
	3	1.2	1.73	–0.67
	4	0.2	1.18	–1.21
Horn status	Horns	9.6	2.23	–0.16
	No horns	89.4	2.41	0.02
Frame	Large	59.0	2.39	0.01
	Medium	40.0	2.39	0.00
	Small	0.8	1.91	–0.48
Fill	Gaunt	16.1	2.52	0.13
	Shrunk	36.1	2.41	0.02
	Average	44.7	2.34	–0.05
	Full	3.0	2.19	–0.20
	Tanked	0.1	1.99	–0.40
	Very thin	0.8	2.16	–0.23
Body condition	Thin	32.4	2.42	0.03
	Average	62.4	2.38	0.00
	Fleshy	4.4	2.25	–0.14
	Fat	0.05	2.08	–0.31
Health status	Sick	0.02	1.37	–1.02
	Lame	0.2	1.51	–0.88
	Stale	0.2	1.92	–0.47
	Bad eye(s)	0.4	2.10	–0.29
	Dead hair	0.3	2.17	–0.22
	Healthy	95.5	2.39	0.00
	Preconditioned	3.2	2.50	0.11

Terms are those typically used for calf descriptions in US industry. Market prices in the USA are reported in $ per 100 lb.
Source: Adapted from Troxel and Barham (2012).

highest for No. 1 to lowest for No. 4, but with much more severe discounts of calves classified as No. 3 or No 4.

Troxel and Barham (2012) evaluated prices of 2010 feeder calves in Arkansas in regard to phenotypic characteristics (Table 5.11). In regard to apparent breed type, severe price discounts were seen for straight Brahman (priced at US$2.07 per kg) and Longhorn (priced at US$1.59 per kg) calves, but other breeds and crosses (including Brahman crosses) were fairly similar in price (US$2.29–2.47 per kg). Prices are most fairly compared within a weight class of calf because there is a typical price 'slide' as animals that weigh more are expected to receive a reduced sale price per unit of weight but remain more valuable. In general, bull calves receive 5–10% lower prices than steers, and heifers receive 10–15% lower prices than steers of the same weight class and other categories. Essentially all bull calves not kept for breeding are castrated in the USA; the percentage of bull calves castrated is likely to be lower in Canada and is probably lower again in Mexico, but exact percentages are not reported.

Prices of both calves and cows and bulls are historically lower in the autumn months (October and November) and higher in the spring (April and May), as the majority of beef herds are spring-calving due to forage resources and environmental conditions. As a result, more calves and culled breeding animals enter the market system close to weaning time in autumn. This is typically when calves are around seven months of age; weaning time is also the most common time for producers to pregnancy-check cows and make culling decisions. As calves can go into stocker programs of feedlots any time, this helps spread the supply of finished feedlot cattle and beef throughout the year. There are many factors that producers can utilise to influence price and value of their calves; simply chasing higher calf price does not guarantee operation profitability. This concept is further discussed below.

Slaughter cattle grades

When North American feedlot cattle are ready for harvest they may be sold on a liveweight basis, on a dressed (carcass weight) basis or on a grid basis (based on carcass grade and weight). If sold live, cattle may be classified for their perceived carcass quality and yield grades (referred to as slaughter cattle grades), which follow the same classification as beef carcass grades (USDA AMS 1996). Quality grades are Prime, Choice, Select and Standard for cattle <30 months old (A maturity classification). The quality grades are estimates of projected consumer palatability. Yield grades are 1, 2, 3, 4 and 5 and represent projected lean meat yield from carcasses. Yield grade 1 cattle have a higher muscle:fat ratio than cattle with higher yield grades. Visual evaluation for yield grade is much more useful than for quality grade. The relative locations of the wholesale cuts of beef in relation to live cattle are provided in Fig. 5.8.

CARCASS GRADES

Beef quality grades are based upon animal age (maturity), amount of intramuscular fat (marbling) and the colour and texture of the muscles. Beef yield grades are based upon carcass weight, external fat cover, degree of muscle expression and internal fat. In general, beef quality grades are used to indicate consumer palatability whereas yield grades are used to predict amount of beef coming from the carcass (Chapter 2).

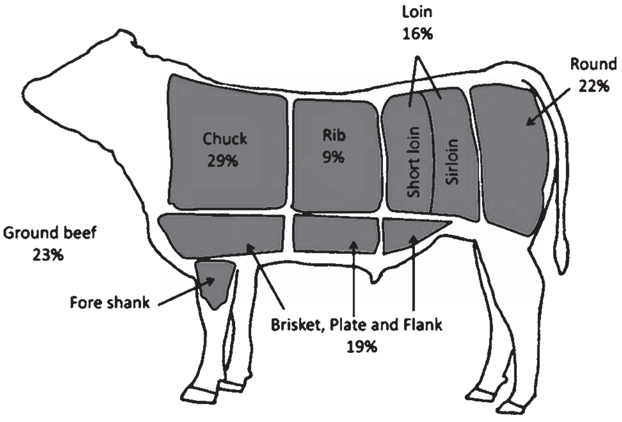


Figure 5.8: Beef wholesale cuts and relative percentage of carcass weight. Carcasses are ribbed between 12th and 13th ribs, separating rib and loin. Source: Adapted from information and graphics of CBB/NCBA (2012).

Both the USA (USDA AMS 1997) and Canadian (CBGA 2012) systems of beef carcass grading are based upon evaluation of a variety of attributes where carcasses are ribbed (cut to separate the fore- and hindquarters) between the 12th and 13th (last two) ribs. At this area, the amount of marbling, external fat thickness and rib eye area (cross-section of *longissimus dorsi* muscle) are evaluated. Since the late 1990s the Canadian quality grading system has utilised the same marbling grades as the US quality grading system, however, Canadian quality grades also consider degree of muscling and external fat cover, which are not factors in determining US quality grades. The marbling scores that dictate quality grades for youthful (<30 months of age) beef carcasses and aspects of yield grade are provided in Table 5.12. In Canada, most beef carcasses are AA and AAA. The same is true in the USA for Select and Choice carcasses, with 90–95% grading in the two categories within each country.

In the US quality grading system there are five maturity level categories (A–E, from youngest to oldest; Fig. 5.9). Cattle that are in the A (<30 months) or B (30–42 months) maturity categories can qualify for the highest quality grades (Choice and Prime). In the Canadian system, carcasses are classified as youthful (<30 months) or mature (>30 months) and only youthful carcasses are eligible for the upper quality grades (A, AA, AAA, and Prime). The requirements for Canadian beef carcass quality grades are detailed in Table 5.13.

Since 2000, the number of US cattle that have been sold on a liveweight or carcass weight basis has fluctuated. In regard to overall cattle sold for slaughter (fed steers and heifers as well as non-fed cows and bulls), selling on a live basis from 2000 to 2010 was less common and ranged from 37% to 48% of transactions, without any particular time-related trend, but a higher percentage of fed cattle were sold on a live basis (50–72%) than cows and bulls (GIPSA 2012). Just because transactions were conducted on a liveweight basis does not mean that carcass grade specifications were not included in the negotiated price, it simply means how the transactions were based.

Futures contracts

The Chicago Mercantile Exchange conducts trade for futures contracts in many commodities and has been in existence since the early 1900s. Producers can utilise these tools in risk management. A futures contract is a

Table 5.12: Comparison of some US and Canadian beef carcass grade attributes

Quality grade			
Marbling score	**Intramuscular fat (%)**	**US quality grade**	**Canadian quality grade**
Abundant	–	Prime	Canada Prime
Moderately abundant	–	Prime	Canada Prime
Slightly abundant	10.13	Prime	Canada Prime
Moderate	7.25	Choice	Canada AAA
Modest	6.72	Choice	Canada AAA
Small	5.04	Choice	Canada AAA
Slight	3.83	Select	Canada AA
Traces	2.76	Standard	Canada A2
Practically devoid	–	Standard	

Yield grade			
USA		**Canada**	
Grade	**Expected yield (%)**	**Grade**	**Expected yield (%)**
1	52.6–54.6	1	≥59
2	50.3–52.3	2	54–58
3	48.0–50.0	3	≤53
4	45.7–47.7		
5	43.5–45.4		

Source: Adapted from BIF (2010); CBGA (2012); Romans *et al.* (2001).

standardised agreement between two parties to buy or sell a specified product of standardised quantity and quality for an agreed price, where delivery and payment occurs at a specified future date. Live cattle (finished feedlot cattle) futures contracts have traded since 1964, feeder cattle futures have traded since 1971 and in 1999 stocker cattle contracts became available. Purchase of these contracts must occur through a licensed dealer or broker. Producers can lock in prices of animals and many feed grains well ahead of anticipated sale or purchase dates through futures. Anyone can trade futures contracts and investment speculators around the world have also traded commodity contracts, which has likely added to price fluctuations. Specific price quotes and commodity contract specifications can be viewed online (CME 2012).

DOMESTIC AND INTERNATIONAL MARKETS

In the USA (since 1988) and Canada (since 2002) there are national beef check-off programs. Through this process, sellers of beef cattle are required to pay US$1.00 per animal at the time of sale. The funds generated from these programs are mandated to be used for research, education and advertising and to improve the overall national beef industry. Both the US and Canadian beef check-off programs have been highly successful in that for each dollar invested there has been a many-fold payoff for industry improvement. In fiscal year 2012, the US beef check-off program had US$ 42.6 million in expenditures; promotions (43.4%), foreign marketing (14.4%), research

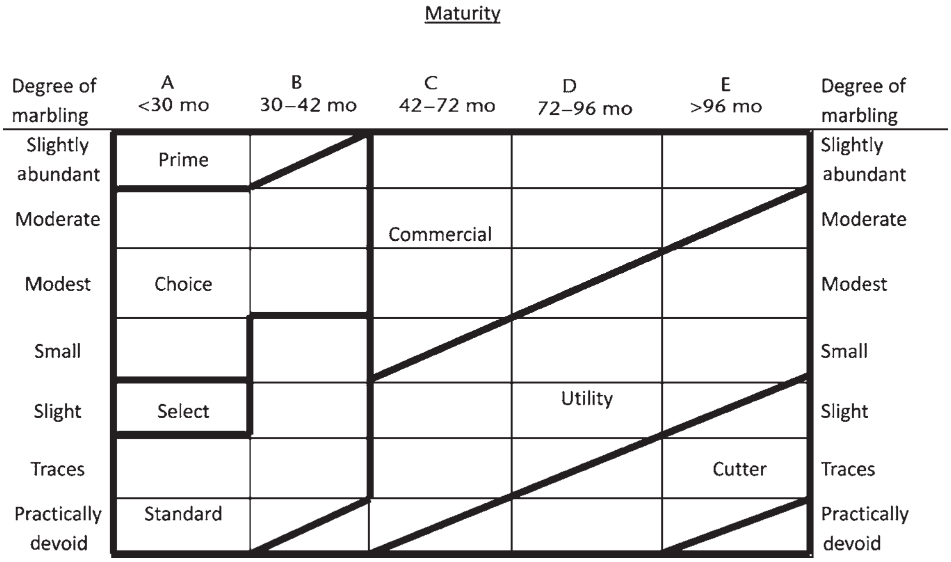


Figure 5.9: Marbling scores and maturity categories associated with US beef carcass quality. Source: USDA AMS (1997).

Table 5.13: Canadian beef quality grades

Grade	Maturity (age)	Muscling	Rib eye muscle	Marbling	Fat colour and texture	Fat measure
Canada Prime	Youthful	Good to excellent with some deficiencies	Firm, bright red	Slightly abundant	Firm, white or amber	≥2 mm
Canada AAA, AA, A	Youthful	Good to excellent with some deficiencies	Firm, bright red	AAA = small AA = slightA = trace	Firm, white or amber	≥2 mm
B1	Youthful	Good to excellent with some deficiencies	Firm, bright red	No requirement	Firm, white or amber	<2 mm
B2	Youthful	Deficient to excellent	Bright red	No requirement	Yellow	No requirement
B3	Youthful	Deficient to good	Bright red	No requirement	White or amber	No requirement
B4	Youthful	Deficient to excellent	Dark red	No requirement	No requirement	No requirement
D1	Mature	Excellent	No requirement	No requirement	Firm, white or amber	<15 mm
D2	Mature	Medium to excellent	No requirement	No requirement	White to yellow	<15 mm
D3	Mature	Deficient	No requirement	No requirement	No requirement	<15 mm
D4	Mature	Deficient to excellent	No requirement	No requirement	No requirement	≥15 mm
E	Youthful or mature	Pronounced masculinity				

Source: CBGA (2012).

(13.4%) and consumer information (10.6%) collectively accounted for 82% of expenditures (CBB 2013).

Beef quality assurance

A major emphasis for the past 20 years in both the US and Canadian beef industries has been beef quality assurance (BQA) programs, funded by beef check-off programs. Principles of BQA have been implemented through various industry segments and a major focus of BQA is to ensure that producers understand the processes, products and considerations that impact consumer acceptability and the potential detrimental effects of not meeting consumer/customer demands. The BQA emphasis in North America has been based on the business philosophy and principles of W. Edwards Deming (Deming Institute 2012), where quality control begins with consistency, and has resulted in best management practices for all industry segments (Fig. 5.10).

Considerable discussion has occurred in recent years regarding the growing world population, the accumulation of wealth in many developing areas of the world and the related increased quantity and quality demands of many food products including beef. In many parts of the world such as Canada, the USA, Australia, New Zealand and western Europe in particular, but also in other affluent areas of the world, there is increasing emphasis

Points from producer code for cattle care:
- Provide adequate food, water and care to protect cattle health and well-being
- Provide disease prevention practices to protect animal health
- Provide facilities that allow safe and humane movement and/or restraint
- Use appropriate methods to euthanase sick or injured animals
- Provide personnel with training to properly handle and care for cattle
- Minimise stress when transporting cattle
- Persons purposely mistreating animals will not be tolerated

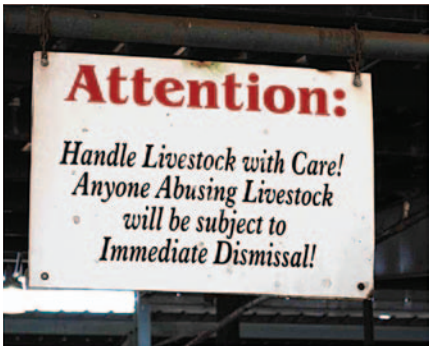


Figure 5.10: On the left are dot points from the Cattle Industry's Guidelines for the Care and Handling of Cattle, developed through partnerships of industry leaders and scientists. On the right is a sign from a cattle sales and distribution yard. Source: CBB/NCBA (2009); www.bqa.org.

on food quality and issues perceived to be related to quality (or satisfaction with purchase) such as genetically modified organisms (GMOs), animal well-being and perceived quality of life and animal rights. Historically, Mexico has preferred a leaner beef product than the typical fed beef of the USA and Canada but growing demand for higher quality product in Mexico is a sign of increased wealth and the ability to emphasise quality. As the Mexican government has placed more emphasis on federal inspection and quality control, it has gained increased international market share and, as a result, there is increased demand for more intramuscular fat content at younger age and more overall domestic beef production. It is in the best interest of an industry to provide a wide array of products that satisfy varying consumer demands (and that are not viewed as competitive). The bottom line on consumer satisfaction is likely delivery of a consistent, desired product at a reasonable price with freedom of information about its manufacture/processing (if desired by the consumer).

International markets

The North American Free Trade Agreement (NAFTA) has provided for livestock and their products to be traded among Canada, Mexico and the USA duty-free since 1994. The relative ability to inexpensively feed cattle in US feedlots has historically resulted in substantial cattle imports from Canada and Mexico. Through the 1990s many Canadian cattle were harvested in the USA, but after the US border was closed due to the Canadian BSE occurrence in 2003, substantial beef harvesting facilities have been built in Canada. The northern states of Mexico (Sonora, Chihuahua, Coahuila) rely on sales of calves destined for US feedlots and have improved management and breeding accordingly. All three nations are major world players in regard to beef cattle production and global export markets; however, they also rely heavily on one another as trade partners (Tables 5.14, 5.15). All three nations have NAFTA partners as primary export and import markets. They have major presence in Asian beef export markets and rely on trade partners of Australia and New Zealand for beef imports.

Table 5.14: Top international markets for 2010 beef exports (and % of total export market) for Canada, Mexico and the USA[1]

Rank	Canada	Mexico[2]	USA
1	USA (75)	USA (65)	Mexico (22)
2	Mexico (11)	Japan (28)	Canada (17)
3	Hong Kong & Macau (5)	Puerto Rico (4)	Japan (15)
4	Japan (4)	South Korea (2)	South Korea (12)
5	Taiwan (<1)	Costa Rica (<1)	Vietnam (5)
Total (kg)	752 million	81 million	1043 million

[1] These are on carcass weight equivalent basis (bone-in) and exclude offal.
[2] Mexico numbers are from 2009.
Source: FAS (2012).

Table 5.15: Top international markets of 2010 beef imports (and % of total imports) into Canada, Mexico and the USA[1]

Rank	Canada	Mexico[2]	USA
1	USA (73)	USA (80)	Canada (31)
2	New Zealand (13)	Canada (16)	Australia (25)
3	Uruguay (6)	Australia (<1)	New Zealand (21)
4	Australia (5)	New Zealand (<1)	Mexico (5)
5	Brazil (4)	Uruguay (<1)	Nicaragua (5)
Total (kg)	179 million	507 million	1042 million

[1] These are on carcass weight equivalent basis (bone-in) and exclude offal.
[2] Mexico numbers are from 2009.
Source: FAS (2012).

PERFORMANCE AND PROFITABILITY MEASURES

Among agricultural products within Canada, Mexico and the USA, sales of beef rank first for total dollar value, with sales of milk also very important (Table 5.16). Many geographical areas within these countries may rely on cattle production almost exclusively for agricultural activity. The relative economic importance of cattle to other agricultural commodities in the USA is illustrated in Fig. 5.11.

The total value of sales shows relative economic importance, but it does not indicate relative profitability. The incidence of selected management practices that are known to influence productivity among US beef cow herds of different sizes (Table 5.17) may or may not dictate

Table 5.16: Economic ranking total production for beef and milk within Canada, Mexico and the USA (2010) among all agricultural commodities

	Cattle meat		Milk	
Country	Rank	Production (million metric tons)	Rank	Production (million metric tons)
Canada	1	1.60	5	8.24
Mexico	1	1.95	3	10.68
USA	1	11.22	2	87.46

Source: FAOSTAT (2012)

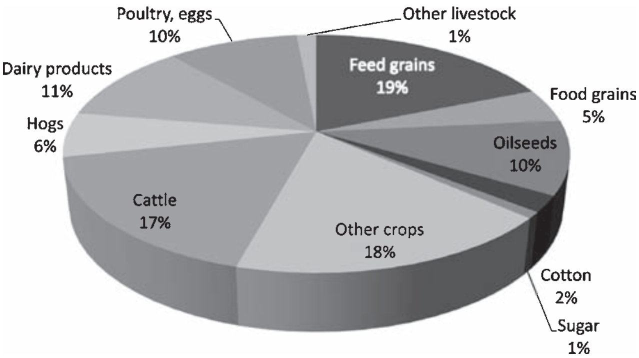


Figure 5.11: Relative distribution of US agricultural cash receipts in 2011. Total receipts were $362.89 billion, with cattle responsible for $69.2 billion. Source: FAPRI (2012).

Table 5.18: Estimated US beef industry margins (profit or loss, US$)* per animal for select years

	Industry segment		
Year	**Cow–calf**	**Feedlot**	**Packer**
2009	26.57	–59.45	–26.73
2007	87.36	–16.47	–9.50
2003	119.94	120.24	6.57
2000	92.06	–27.42	7.67
1996	–112.20	–13.14	14.74
1991	81.26	–56.49	–7.08
1988	107.70	19.78	–14.62

* Nominal values by year.
Source: AMI (2011).

profit, but are definitely incorporated by larger producers that are expected to be profit-driven. Producers must match all aspects of genetics, environment, management and marketing in order to generate profitability.

Cattle production is a very capital-intensive activity, and it typically has been accomplished within an industry with low profit margins on a per animal basis (Table 5.18). The traditional model in the USA has been for cow–calf producers to sell animals to stocker operators or feedlots (stocker operators sell to feedlots) and feedlots to sell to packers (then packers sell to wholesalers or retailers). In some years several segments are profitable, in some years several or all segments lose money, and in many years profit across industry segment is variable. A wide host of factors affect profitability each year.

Table 5.17: Percentage of US beef cow operations performing selected management practices by herd size (2007)

	Herd size (no. of breeding cows)			
Practice	**1–49**	**50–99**	**100–199**	**200+**
Castration of male calves	50.3	75.0	85.1	95.3
Provided calf health information to buyers	28.2	43.4	57.5	74.0
Attended BQA meetings or training	45.7	72.9	66.3	62.6
Palpation for pregnancy	10.8	25.8	41.2	58.3
Artificial insemination	5.6	8.4	16.3	19.8
Semen evaluation of bulls before previous season	18.1	41.7	51.6	61.1
Utilised hormone growth implants in calves	7.0	19.9	27.3	31.1

Source: USDA NAHMS (2008, 2009, 2010).

North American cattle producers who can capitalise on specialised sales to be paid in value-added concepts (including consumer education) and can provide uniformity of product (within and across time) are most likely to stay in business. Increased regulatory costs and consumer misguidance are potential threats to the economic sustainability of many components of North American cattle production and are further discussed below.

Since the early 1990s, there has been an organised effort – Integrated Resource Management (IRM) and Standardised Performance Analysis (SPA) – to standardise and combine financial and performance data for cow–calf producers. These have been tailored to specific geographical regions or states. The procedure uses an accrual accounting rather than a cash accounting approach, and therefore produces different estimates of profitability because it factors in depreciation and charges rent for land use even when owned by the operator. The profitability for average, least profitable and most profitable beef cow operations for different regions and time frames is provided in Table 5.19. Across geographic regions and times, producers who are the most profitable in SPA analyses are those that can 1) monitor and minimise annual feeding expenses and 2) are good at regular planning, monitoring and incorporating flexibility. There are typically differences in animal performance (e.g. weaning rate, weaning weight etc.) and animal prices in favour of the most profitable operations, but those are not nearly as important in dictating profit as feed and operating costs (TCE 2003; Dhuyvetter and Langemeier 2010).

Table 5.19: Profitability from SPA databases in different regions and times

	Annual net return US$ per cow			
Region* and time	**Average**	**Least profitable**	**Most profitable**	**Criteria for profitability groups**
OK, TX, NM, 1991–2002	–33	–261	140	Bottom and top 1/4
Kansas,2004–08	–152	–356	15	Bottom and top 1/3
MI, MN, MO, ND, NE, OH, SC, S.D., UT, WI, 2008–11	–27	–429	207	Bottom and top 1/5

* Oklahoma, Texas, New Mexico, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, South Carolina, South Dakota, Utah, Wisconsin.
Source: Adapted from *Dhuyvetter and Langemeier (2010)*, FINBIN (2012) and TCE (2003).

It is expected that profitability will remain strong among US cow–calf producers through 2015 due to high cattle prices and a restricted number of animals; retail beef prices are not expected to decrease (Fig. 5.12).

FUTURE TRENDS, CONSTRAINTS AND OPPORTUNITIES

There are several occurring and emerging trends in North America (and the world) that will likely play a role in North American beef production, and all industry participants should be knowledgeable about them. Factors affecting these trends are interrelated and have many different and interacting components; however, for simplicity these factors are classified here as 1) public opinion and societal concerns, 2) production costs, and 3) cattle numbers. These are discussed below.

Public opinion and societal concerns

The USA and Canada are similar to western Europe, Australia, New Zealand, Japan and other geographical areas where there is enough wealth that many consumers can make purchases driven by emotional aspects of production (and their perceptions thereof) in addition to price and quality. Many technologies provide increased production efficiency, producing more beef product with limited land and feed resources and decreasing animal numbers. These include growth promoting implants (hormonally based on oestrogen, progesterone and a synthetic form of testosterone, trenbalone acetate; Reinhardt 2012), feed additives such as ionophores (which alter the rumen microbial population for improved energetic efficiency; Herdt and Perry 2011) and β-agonists (which alter cellular function for increased muscle mass; Buchanan-Smith, 2013). There is much discussion and public concern about use of feed-grade antibiotics in livestock production and microbial resistance, but the scientific evidence does not provide consistent, clear-cut relationships and many people may not realise that not following a physician's prescription for human antibiotic use contributes to microbial resistance (Leung *et al*. 2011; CDC 2012). It is crucial to provide consumers with products they desire, but it is also important to provide factual information, to consider the entire production system and to have open dialogue within and across industry segments.

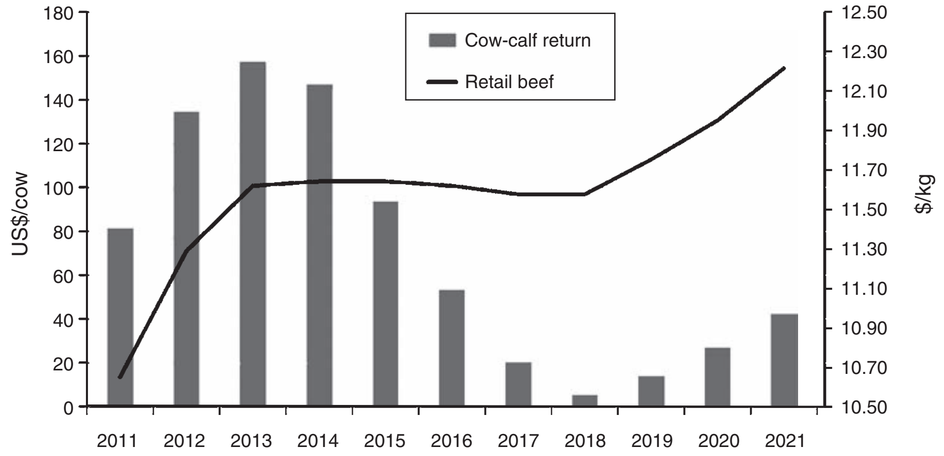


Figure 5.12: Projected US annual cow–calf returns and retail beef price. Source: FAPRI (2012).

Many opinions in the public press have stated that there are increased hormone concentrations in implanted *v.* non-implanted beef, which is true, but the increase is minuscule compared to oestrogenic differences across a wide range of vegetable or other food products. Few people seem to be aware that oestrogen levels in municipal wastewater from widespread use of birth control pills may affect the life cycles of aquatic animal species and have very large environmental impacts (Ternes *et al.* 1999; Kidd *et al.* 2007). In the first part of 2012, public reports and discussion about lean, finely-textured beef (LFTB) were prevalent. This was a product that had been approved and utilised for over 20 years in the USA; however, the media disapproved and dubbed it 'pink slime.' The growing public distrust fuelled by media reports led to the product's voluntary termination by the beef industry. The process had allowed 12–18 kg of beef per animal to be separated from fat trimmings that had otherwise gone unrecovered, and added up to US$30 of value to each beef carcass (Greene 2012). Public opinion was swayed by incomplete and inaccurate reports in the media and internet blog posts. It is likely that many areas of the world that need the improved technologies for improved production efficiency do not have the industry infrastructure or regulatory oversight to take advantage of them. Conversely, in many areas that do have these capabilities, the lack of media or consumer understanding and/or the motives of media or activist groups to harm an industry prevent their use (and can reduce efforts to discover new technology). In the long run this is expected to drive up costs for everyone. It is unclear why agriculture seems to be such a popular target for blame on many issues, but is likely due to many people being unfamiliar with typical production practices and not thinking about issues from a total systems perspective.

It is good for the North American beef industry to produce and provide a variety of products for consumers and, as long as consumer decisions are based on factual information, the industry is strengthened. In societies where only a very small proportion of the population is familiar with production-level agriculture (e.g. in wealthy societies), there is increased potential for misinformation and misperceptions to be formed and propagated, and lead to legislation that does the wrong thing out of the right intentions. Communication and open-mindedness are critical. Smith *et al.* (2008) described the concept of 'story' beef, meaning that many consumers are interested in knowing about the production processes involved; this may be a reflection of their desire for knowledge (or their perception) about safety or wholesomeness or animal welfare. This has led to the desire for natural, organic and or grass-fed beef by some North American (and other) consumers, and in many cases has promoted source- and process-verified programs even among conventional products.

Cattle producers in North America care about economic, societal and ecological sustainability (ERS 2012). Many have adopted best management practices such as BQA even when there are no direct economic incentives, simply because they believe 'it's the right thing to do', and several industry groups promote and provide awards for environmental stewardship. This overall attitude of stewardship seems to be common for most agricultural operators and land owners, even among large corporate entities, which is not what the public may be led to believe. ERS (2012) reported that US commercial fertiliser and pesticide use has been steady or declining in recent years, due to improvements in technology and other factors. It was also reported that the number of livestock operations has fallen and production has shifted to larger and more specialised operations, and that changes in livestock production have had important implications for production efficiency, value-added considerations which can be tied to environmental stewardship, food safety and rural development in general (ERS 2012).

Policy impacts on cost of production

Since the 1970s, the US and Canadian beef production systems have been based on feeding grain to young cattle (steers and surplus heifers). This is a highly intensive production system in that animals are confined in feedlots with multiple daily feeding, and animal observation is needed. It is also very capital (money) intensive. It allows the production of more beef per unit of land in the shortest amount of time compared to forage-based systems, and has been based on relatively cheap sources of feed grains and various feed co- or by-products. Its sustainability relies on the economic, environmental and societal conditions. Regulatory compliance is a major responsibility for large confined animal feeding operations.

In the mid 2000s the US government mandated (via the *Energy Policy Act 2005* and *Energy Independence and Security Act 2007*) for the production of a specified amount of ethanol from plants because it was viewed as a 'green' energy source, with as much as 56.8 billion L (15 billion gallons) of starch-based ethanol (mostly from corn) in the USA by 2015. In 2005–06, 17 billion L

(4.5 billion gallons) of ethanol were produced, by 2008–09 production increased to 38.6 billion L (10.2 billion gallons) and it rose to 47.3 billion L (12.5 billion gallons) in 2009–10 (Hoffman and Baker 2011). As a result, the price of corn dramatically increased, which was bad for people feeding livestock but good for corn farmers as more corn has been used for ethanol production. From the mid 1970s until 2005, US corn prices generally fluctuated between US$2.00 and $3.00 per bushel, but since 2005 prices have increased dramatically and fluctuated from $5.50 to $6.50 per bushel. In general, all commodity prices have become both inflated in price and more volatile in recent years, and many industry analysts have anticipated that access to operating capital will be a challenge for many agricultural entities. The North American food industries (and many other goods) are highly dependent upon transportation, and the beef industry is dependent upon trucking for movement of animals and products. The cost of row crop and grain production is also highly dependent upon fuel for land preparation, planting and harvesting, and marketing and transportation by truck and railway.

Operating capital to cope with wide fluctuations and volatility in commodity prices must be at the centre of managers' minds. In 2011, change in fed cattle prices often resulted in change of US$40 or more per animal from one week to the next (CattleFax 2012). Capital investment to feed cattle (due to animal and feed prices) increased from US$170 per animal in 2000 to over US$300 per animal in 2012, and it was estimated that it took 60% more capital to operate a cow–calf operation in 2012 than in 2000 and 60% more capital to manage a feedlot in 2012 since 2009 (CattleFax 2012).

Many people believe that use of grazing lands is a more environmentally friendly endeavour than grain-finishing and confinement feeding, or that it is healthier. A 2011 study which properly accounted for complete livestock production system inputs and outputs showed that intensive production systems may have smaller carbon footprints than many types of production that most people would consider more 'green' (Capper 2011). In the USA and Canada, grass-fed beef and/or organic production is a niche product in that it is a small proportion of total production. Numerous studies (Dangour *et al.* 2010) have shown no health or nutritional advantages of organic products over conventional products when all other factors are equal. Many believe that grass-fed beef is healthier than grain-fed beef, but the correct answer depends upon which aspect is being compared. Grass-finished beef tends to be leaner and to have increased levels of some desirable fatty acids, but the actual difference is quite small, especially compared to other protein foods such as fish (Abbas *et al.* 2009; Chapter 2). With proper portion control, grain-fed beef is equally healthy (Daley *et al.* 2010). The shelf life, appearance and taste may be quite different for beef produced in different production systems. Beef consumption provides an important protein source when consumers follow guidelines such as the food pyramid (USDA 2012) for balanced diets within recommended caloric levels.

Animal numbers

The feedlot industry, beef packing industry and beef product components of grocery and food service rely on the cow populations that produce cattle. Cattle numbers in both Canada and the USA have decreased in recent years (Fig. 5.13). The decrease in cow numbers has resulted from a variety of factors such as regional droughts, increased feed costs and increased demands on rural lands for recreational uses. US cow numbers in 2013 were the lowest since the early 1950s. In Canada, from 2006 to 2011 the number of breeding beef cows and replacement heifers decreased by 22.3% and the number of farms reporting beef breeding stock decreased by 25.3% (Statistics Canada 2012). Between the US national agricultural census of 2002 and 2007, ~6.5 million ha of agricultural land were taken out of production (1.6% of total calculated from Table 5.3), yet the population increased by 13.8 million people (287.8 million to 301.6 million; US Census Bureau 2012) during this time. Part of this loss of agricultural lands is directly due to population increase, but it is also related to how urban and suburban areas grow, expanding at a much higher percentage in land area relative to percentage population increases (Heimlich and Anderson 2001). As population increases occur, there is a corresponding increase in value of rural lands, which is a mixed blessing for land owners. CattleFax (2012) reported that US land prices had increased 200% from 2000 to 2011, but regionally the rise may be 400% or more. For many years the value of US agricultural lands in many regions has been dictated by non-agricultural uses such as recreation, fossil fuel potential, proximity to urban areas and potential for suburban development. Increased land valuation also produces increased taxation. The choice between keeping the land (which commonly has been held by a family for many generations) with a decreasing profit margin, or selling it, causes considerable angst in many agricultural families. Many people interested in

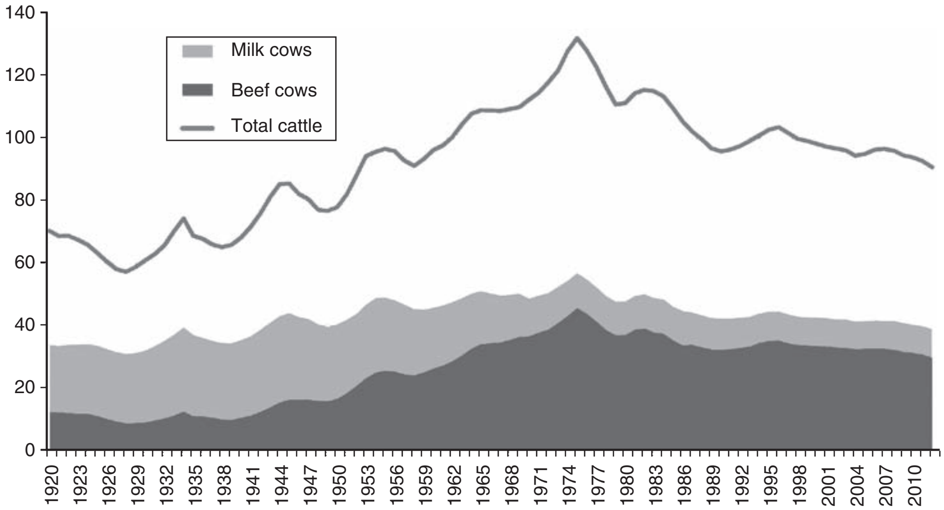


Figure 5.13: US inventory (in millions) for total cattle, and cows from 1920 to 2012. In the early part of the 20th century milk cows outnumbered beef cows ~3:1, but the reverse has been the case since the mid 1970s. Source: NASS (2012), based on 1 January inventories.

conservation of various natural resources (water, plant and animal species, undeveloped forests, deserts etc.) do not seem to consider conservation of rural and agricultural lands in the same light when they are adjacent to existing municipal areas.

Sustainability of North American beef production

Numerous opportunities exist for North American beef cattle producers. Strong points for the industry include 1) increased numbers of markets for beef products, 2) recognition of grain-based finishing as producing high-quality products, 3) increased meat demand in many areas of the world, 4) numerous and varied domestic and international markets, 5) many areas where grazing of cattle is possible and may be the best economic use of the land for balanced productivity and environmental stewardship, and 6) continual improvement in product and process satisfaction through beef quality assurance efforts. Challenges include 1) increased costs of production and associated volatility in commodity prices, 2) activist groups that are interested in promoting agenda issues rather than engaging in science-based discussions, 3) education of consumers who are potentially bombarded with tremendous amounts of information, 4) legislative and judicial personnel that are far removed from an accurate understanding of production agriculture, and 5) loss of agricultural lands due to urban and suburban development. For a detailed discussion on the considerations for sustainability of North American beef production see Galyean *et al*. (2011).

It is critical for North American beef industry participants to 1) promote openness in all production components to meet increased animal welfare, food safety and environmental public concerns, 2) study, understand and proactively engage their customers, 3) have access to and provide factual data to law-makers and 4) have access to fair and openly competitive markets. Consumer and producer science-based education, as well as open communication, are critical for the sustainability of North American beef production.

REFERENCES

AAA (2012) American Angus Association. < http://www.angus.org/pub/Anghist.aspx>.

Abbas KA, Mohamed A, Jamilah B (2009) Fatty acids in fish and beef and their nutritional values: a review *Journal of Food Agriculture and Environment* **7**, 37–42.

AHA (2012) American Hereford Association. <http://hereford.org/node/47>.

AMI (2011) *Livestock Marketing Fact Sheet*. American Meat Institute. <http://MeatAMI.com>.

ASA (2012) American Shorthorn Association. <http://www.shorthorn.org/breedinfo/about/history_about_breedinfo.html>.

Ball CE (1992) *The Finishing Touch: A History of the Texas Cattle Feeders Association and Cattle Feeding in the Southwest*. Texas Cattle Feeders Association, Amarillo, TX.

BIF (2010) *Guidelines for Uniform Beef Improvement*. 9th edn. Beef Improvement Federation. <http://www.beefimprovement.org>.

Buchanan-Smith J (2013) Optimizing feedlot feed efficiency Beef Cattle Research Council of Canada <http://www.beefresearch.ca/research-topic.cfm/optimizing-feedlot-feed-efficiency-8>.

CAA (2012) Canadian Angus Association. <http://www.cdnangus.ca/about/breed_history.htm>.

CANFAX (2011) *Statistical Briefer*. CANFAX Research Services, Calgary, Alberta. <http://www.canfax.ca/Samples/StatBrf.pdf>.

Capper JL (2011) Replacing rose-tinted spectacles with a high-powered microscope: the historical versus modern carbon footprint of animal agriculture *Animal Frontiers* **1**, 26–32. doi:10.2527/af.2011-0009.

CattleFax (2012) 2012 industry outlook. Presented at 2012 National Cattlemen's Beef Association annual meeting, February. Nashville, TN.

CBB (2013) *2012 Annual Report*. Cattlemen's Beef Board. <http://www.beefboard.org/financial/files/Final%20pdf%20010313.pdf>.

CBB/NCBA (2009) *Beef Quality Assurance Program* and *Animal Welfare Fact Sheet*. Cattlemen's Beef Board/National Cattlemen's Beef Association. <http://wwwExploreBeef.org>.

CBB/NCBA (2012) Cattlemen's Beef Board/National Cattlemen's Beef Association. <http://beefretail.org>.

CBGA (2012) Canadian Beef Grading Agency. <http://www.beefgradingagency.ca>.

CCIA (2012) Canadian Cattle Identification Agency. <http://www.canadaid.com>.

CDC (2012) *Antibiotic Resistance Questions & Answers*. US Centers for Disease Control and Prevention. <http://www.cdc.gov/getsmart/antibiotic-use/antibiotic-resistance-faqs.html>.

CHA (2012) Canadian Hereford Association. <http://www.hereford.ca>.

CME (2012) Chicago Mercantile Exchange Listing of Commodity Products. <http://www.cmegroup.com/product-codes-listing/commodities-codes.html>.

CSA (2012) Canadian Shorthorn Association. <http://www.canadianshorthorn.com/breed_history.html>.

Daley CA, Abbott A, Doyle PS, Nader GA, Larson S (2010) A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutrition Journal* **9**, 10. doi: 10.1186/1475-2891-9-10<http://www.nutritionj.com/content/9/1/10>.

Dangour AD, Lock K, Hayter A, Allen E, Uauy R (2010) Nutrition-related health effects of organic foods: a systematic review *American Journal of Clinical Nutrition* **92**, 203–210. doi:10.3945/ajcn.2010.29269.

Deming Institute (2012) W. Edwards Deming Institute. <http://deming.org>.

Dhuyvetter K, Langemeier M (2010) *Differences between High, Medium, and Low Profit Cow–calf Producers: An Analysis of 2004–2008 Kansas Farm Management Association Cow–calf Enterprise*. Department of Agricultural Economics, Kansas State University. <http://www.agmanager.info>.

ERS (2012) *Crop and Livestock Practices*. US Department of Agriculture, Economics Research Service. <http://www.ers.usda.gov/topics/farm-practices-management/crop-livestock-practices.aspx>.

FAOSTAT (2012) Country profiles and searchable databases. Food and Agriculture Organization of the UN. <http://faostat.fao.org/site/291/default.aspx>.

FAPRI (2012) *US Baseline Briefing Book: Projections for Agricultural and Biofuel Markets*. FAPRI-MU Report #01–12, Food and Agricultural Policy Research Institute, University of Missouri. <http://www.fapri.missouri.edu/outreach/publications/2012/FAPRI_MU_Report_01_12.pdf>.

FAS (2012) Searchable databases. US Department of Agriculture, Foreign Agricultural Service. <http://www.fas.usda.gov/data.asp>.

FINBIN (2012) *FINBIN: Farm Financial Database*. <http://www.finbin.umn.edu>.

Galyean ML, Ponce C, Schutz J (2011) The future of beef production in North America *Animal Frontiers* **1**, 29–36. doi:10.2527/af.2011-0013.

GIPSA (2012) *2011 P&SP Annual Report*. Grain Inspection, Packers and Stockyards Administration. US Department of Agriculture, Packers and Stockyards Program. This and other reports available: <http://www.gipsa.usda.gov>.

Greene JL (2012) *Lean Finely Textured Beef: The 'Pink Slime' Controversy*. US Congressional Research Service 7–5700. <http://www.crs.gov R42473>.

Heimlich R, Anderson W (2001) *Development at the Urban Fringe and Beyond: Impacts on Agriculture and Rural Land.* Agricultural Economic Report No. AER-803. <http://www.ers.usda.gov/publications/aer-agricultural-economic-report/aer803.aspx>.

Herdt TH, Perry TW (2011) Performance modifiers in beef cattle. Merck Veterinary Manual Online. <http://www.merckmanuals.com/vet/management_and_nutrition/nutrition_cattle/performance_modifiers_in_beef_cattle.html>.

Hoffman LA, Baker A (2011) *Estimating the Substitution of Distillers' Grains for Corn and Soybean Meal in the U.S. Feed Complex*. Report FDS-11-I-01. US Department of Agriculture, Economic Research Service.

IMI Global (2012) <http://www.imiglobal.com>.

Kidd KA, Blanchfield PJ, Mills KH, Palace VP, Evans RE, Lazorchak JM, Flick RW (2007) Collapse of a fish population after exposure to synthetic estrogen *Proceedings of the National Academy of Sciences of the USA* **104**, 8897–8901. doi:10.1073/pnas.0609568104.

Leung E, Weil DE, Raviglione M, Nakatani H, World Health Organization World Health Day Antimicrobial Resistance Technical Working Group (2011) The WHO policy package to combat antimicrobial resistance. *Bulletin of the World Health Organization* **89**, 390–392. doi:10.2471/BLT.11.088435.

MacDonald JM, McBride WD (2009) *The Transformation of US Livestock Agriculture: Scale, Efficiency, and Risk*. Economic Information Bulletin No. 43. US Department of Agriculture, Economic Research Service. <http://www.ers.usda.gov/publications/eib43/>.

MacDonald J, Ollinger M, Nelson K, Handy C (1999) *Consolidation in US Meatpacking.* Agricultural Economic Report No. AER-785, March 1999. <http://www.ers.usda.gov/publications/aer-agricultural-economic-report/aer785.aspx>.

McBride WD, Mathews K Jr (2011) The diverse structure and organization of US beef cow–calf farms. Economic Information Bulletin No. 73. US Department of Agriculture, Economic Research Service.

NAGP (2012) National Animal Germplasm Program. US Department of Agriculture, Agricultural Research Service. <http://www.ars.usda.gov/SP2UserFiles/Place/54020500/documents/NAGP.pdf>.

NASS (2012) US Department of Agriculture, National Agricultural Statistics Service. <http://www.nass.usda.gov>.

National Pedigreed Livestock Council (2012) < http://www.nplc.net/>.

Ortega C, Peel DS (2010) The Mexican animal identification system: current situation, problems, and potential. *Journal of Agricultural and Applied Economics* **42**, 551–557.

OSU (2012) *Breeds of Livestock*. Department of Animal Science, Oklahoma State University. <http://www.ansi.okstate.edu/breeds/>.

Peel DS, Johnson RJ, Mathews KS Jr (2010) *Cow–calf Beef Production in Mexico*. LDP-M-196–01. US Department of Agriculture, Economic Research Service. <http://www.ers.usda.gov/Publications/LDP/2010/10Oct/LDPM19601/>.

Peel DS, Mathews KS Jr, Johnson RJ (2011) *Trade, the Expanding Mexican Beef Industry, and Feedlot and Stocker Cattle Production in Mexico*. Report LDP-M-206–01. US Department of Agriculture, Economic Research Service.

Powell J (2009) *Livestock Health Series: Bovine Respiratory Disease*. Pubn No. FSA3082-PD-2–04N. Cooperative Extension Service, University of Arkansas. <http://www.uaex.edu/Other_Areas/publications/PDF/FSA-3082.pdf>.

Reinhardt CD (2012) Steroid hormones. Merck Veterinary Manual Online. <http://www.merckmanuals.com/vet/pharmacology/growth_promotants_and_production_enhancers/steroid_hormones.html#v4694722>.

Romans JR, Costello WJ, Carlson CW, Greaser ML, Jones KW (2001) *The Meat We Eat*. 14th edn. Interstate Publishers, Danville, IL.

Sanders JO (1980) History and development of Zebu cattle in the United States. *Journal of Animal Science* **50**, 1188–1200.

SINIIGA (2012) Sistema Nacional de Identificación Individual de Ganado. <http://www.siniiga.org.mx>.

Smith GC, Tatum JD, Belk KE (2008) Trends in value-added marketing; challenges and similarities among branded beef products; importance of animal welfare. In *Proceedings of the Beef Improvement Federation 40th Annual Research Symposium & Annual Meeting*. pp. 18–20. <http://www.beefimprovement.org/PDFs/2008_BIF_Proceedings.pdf>.

Sponenberg DP, Olson TA (1992) Colonial Spanish cattle in the USA: history and present status. *Archivos de Zootecnica* **41**, 401–414.

Statistics Canada (2012) *Highlights and Analysis: Snapshot of Canadian Agriculture*. <http://www.statcan.gc.ca/ca-ra2011/index-eng.htm>.

TCE (2003) *Standardized Performance Analysis for Southwest Herds, 1991–2002*. Texas Cooperative Extension, Department of Agricultural Economics, Texas A&M University. 17 July 2003.

Ternes TA, Stumpf M, Mueller J, Haberer K, Wilken RD, Servos M (1999) Behaviour and occurrence of estrogens in municipal sewage treatment plants. I. Investigations in Germany, Canada and Brazil. *Science of the Total Environment* **225**, 81–90. doi:10.1016/S0048-9697(98)00334-9.

Troxel TR, Barham BL (2012) Phenotypic expression and management factors affecting the selling price of feeder cattle sold at Arkansas livestock auctions. *Professional Animal Scientist* **28**, 64–72.

US Census Bureau (2009) Population Division Table 1. *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico*: *April 1, 2000 to July 1, 2009*. NST-EST2009–01. <http://www.census.gov/popest/data/historical/index.html>.

US Census Bureau (2012) Various reports for business code ‘NAICS 311611: Animal (except poultry) slaughtering’. <http://www.census.gov/econ/industry/current/c311611.htm>.

USAC (2012) US Agricultural Census. <http://www.agcensus.usda.gov>.

USDA (2012) *Food Pyramid and Recommended Dietary Guidelines*. US Department of Agriculture. <http://www.choosemyplate.gov/>.

USDA AMS (1996) *United States Standards for Grades of Slaughter Cattle*. US Department of Agriculture, Agricultural Marketing Service.

USDA AMS (1997) *United States Standards for Grades of Carcass Beef*. US Department of Agriculture, Agricultural Marketing Service.

USDA AMS (2000) *US Standards for Grades of Feeder Cattle*. AMS-586. October 2000. US Department of Agriculture, Agricultural Marketing Service.

USDA ARS (2012) *Plant Hardiness Zone Information*. US Department of Agriculture, Agricultural Research Service. <http://planthardiness.ars.usda.gov/PHZMWeb>.

USDA NAHMS (2008) *Beef 2007–08. Part I: Reference of Beef Cow–calf Management Practices in the United States, 2007–08*. US Department of Agriculture, Animal and Plant Health Inspection Service. <http://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/>.

USDA NAHMS (2009) *Beef 2007–08. Part II: Reference of Beef Cow–calf Management Practices in the United States, 2007–08*. US Department of Agriculture, Animal and Plant Health Inspection Service. <http://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/>.

USDA NAHMS (2010) *Beef 2007–08. Part IV: Reference of Beef Cow–calf Management Practices in the United States, 2007–08*. US Department of Agriculture, Animal and Plant Health Inspection Service. <http://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/>.

USDA NASS (2011a) *Cattle on Feed Report*. 21 January. US Department of Agriculture, National Agricultural Statistics Service.

USDA NASS (2011b) *Cattle Report*. 28 January. US Department of Agriculture, National Agricultural Statistics Service.

USDA NASS (2012) Searchable databases. US Department of Agriculture, National Agricultural Statistics Service. <http://www.nass.usda.gov/Data_and_Statistics/index.asp>.

World Bank (2012) Searchable databases. <http://data.worldbank.org>.

6 Brazilian beef production

P.V.R. Paulino and M.S. Duarte

HISTORY AND EVOLUTION OF THE BEEF CATTLE INDUSTRY IN BRAZIL

Brazilian agriculture plays an important role in the food commerce of the world and beef production is one of the main agribusinesses. Currently ranking as the second-largest beef producer in the world, Brazilian beef production has shown a rapid increase in the 50 years since 1960, achieving a herd of over 200 million head (Torres Jnr and Neto 2012). However, the beef industry in Brazil is characterised by dispersion and lack of integration. This is unlike the Brazilian poultry industry, which has been developed around the concept of strategic groups for commodities and specialties (i.e. processed products), and is characterised by the use of technology to achieve high productivity (Oiagen 2010).

In the early 1960s the Brazilian beef cattle herd was 55.7 million head, reaching 215.2 million head in 2011 (Torres Jnr and Neto 2012). According to the last Census of Agriculture conducted by the Ministry of Agriculture, in 2006, there were exactly 5 175 489 ranches and farms in Brazil, occupying 329 941 393 ha. Cattle production took place on 30% of those properties. Between 1961 and 1971, Brazil's beef cattle herd grew at 45.6% (55.7 million to 81.1 million head) and from 1971 to 1981 there was an increase of 46.4% (81.1 million to 150 million) – the greatest increase of the beef cattle herd (Fig. 6.1). This large increase occurred due to the rapid industrialisation in Brazil from the 1960s until the 1980s, leading to important challenges imposing pressure on the agriculture sector (Pereira *et al.* 2012). An important increase in beef demand followed the industrialisation process.

From 1961 to 2011, beef cattle slaughter increased from 7.2 million to 41.4 million head (Torres Jnr and Neto 2012). Within this period new technologies were developed and adopted by Brazilian beef producers to improve the efficiency of production (Chapter 4). Consequently, the average carcass weight and the amount of beef produced increased more than five-fold from 1.37 million tons of carcass weight equivalent (CWE) in 1961 to 9.4 million in 2012 (Fig. 6.2).

Beef cattle production in Brazil is based on pastures which represent the lowest cost food resource for ruminant feeding (Sampaio *et al.* 2010; Chapters 16, 18). Although the number of feedlots is increasing, the Brazilian beef production system can still be considered 'grass-fed' animals, since they are kept in the feedlot for a very short time, mainly at the finishing period (Fries and Ferraz 2006; Chapters 4, 11). The production costs of beef in Brazil are estimated to be 60% lower than in Australia and 50% lower than in the USA, which makes the Brazilian beef system highly competitive in the international beef market. In 1961, Brazil exported only 2.6% of the total beef produced, increasing to 17% in 2012 (ABIEC 2011; Torres Jnr and Neto 2012).

Even though Brazil has a large beef production industry in a competitive international beef market, industry statistics hide large differences between regions within the country. The beef cattle industry located in more developed areas of the country has experienced considerable modernisation along with expansion of a dynamic agribusiness sector, such as corn and soybean farms, ethanol plants, soybean crushing plant and orange

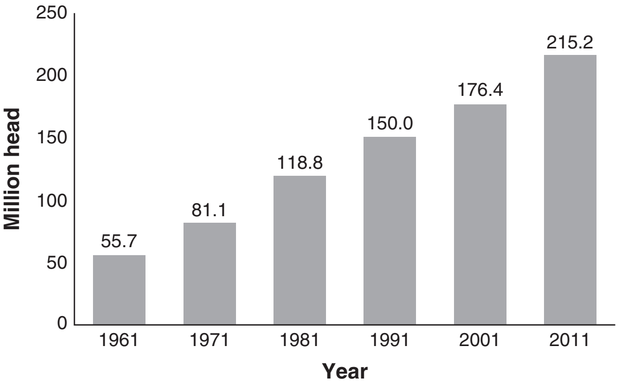


Figure 6.1: Brazilian beef cattle herd from 1961 to 2011. Source: Adapted from Torres Jnr and Neto (2012).

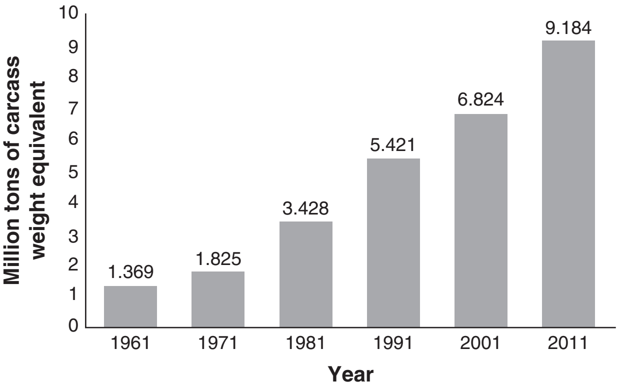


Figure 6.2: Evolution of Brazilian beef production from 1961 to 2011. Source: Adapted from Torres Jnr and Neto (2012).

juice plants, all providing by-products that can be used for beef production (Somwaru and Valdes 2004).

Animal welfare has been an important issue for the Brazilian beef cattle supply chain. Most of the exporting packing plants are required to have some source of animal welfare program for handling, shipping, transportation and humanitarian slaughtering. The programs are audited by international experts to make sure the packing plants are in compliance with the requirements established by most of the foreign markets. On the production side, most ranchers have adopted strategies to promote farm animal welfare, as they are concerned with the impact it has on animal production, carcass and meat quality traits. In this regard, training of truck drivers, cowboys and packing plant employees has been used very intensively lately in Brazil. Manuals of good animal practices during vaccination, loading cattle and transportation were published recently by an important Brazilian university, to educate cattle producers.

On the sustainability side, new programs have been developed through the GTPS (Working Group on Sustainable Beef) initiative. The BRSL (Brazilian Roundtable on Sustainable Livestock) was created in late 2007 and formally constituted in June 2009. It consists of representatives from different sectors that make up the value chain of cattle production in Brazil. It is attended by representatives of industries and industry organisations, associations of ranchers, retailers, banks, civil society organisations, research centres and universities. The goal is to discuss and formulate, in a transparent manner, principles, standards and common practices to be adopted, which contribute to the development of sustainable cattle ranching, which are socially fair, environmental friendly and economically viable. The involvement and engagement of all segments that make up the beef cattle supply chain, and civil society, is fundamental to achieving this goal.

Another example related to sustainable beef production in Brazil is the project called ‘Pecuaria Verde’ (Green Beef). This project began in 2009, involving a group or ranchers from Paragominas, a city in the state of Para in north Brazil, in the heart of the Amazon region. The goal was to implement a model of cattle ranching that is socially fair and in total compliance with Brazilian environmental legislation. By adopting technologies, productivity would increase and ranching would become an economically feasible activity, without disturbing the Amazon forest. The project was conceived by the Paragominas Cattlemen Association and was funded by a couple of private companies and two non–governmental organisations (The Nature Conservancy and Imazon). It changed the regional way of thinking, as it showed it was possible to link cattle production and environment conservation.

PRODUCTION SYSTEMS IN DIFFERENT REGIONS OF BRAZIL

Beef cattle production systems in Brazil vary among the different regions. Although cattle production occurs in all regions, it is generally concentrated in the northern, north-eastern, southern, south-eastern and central regions (Ferraz and Felício 2010), where five states account for half the area used for beef production (Table 6.1).

Beef production in Brazil can be divided into three primary types: grass-fed small enterprises, grass-fed medium specialised operations, and grain-fed/grass-fed large commercialised beef operations. The ‘small beef

Table 6.1: Total area used for beef cattle (ha)

States	Total area (thousand ha)	Participation (%)*
Mato Grosso	22 715	13.89
Minas Gerais	20 437	12.49
Mato Grosso do Sul	18 019	11.02
Goiás	14 986	9.16
Pará	14 386	8.80
Bahia	12 822	7.84
Tocantins	10 232	6.26
Rio Grande do Sul	8562	5.23
São Paulo	7798	0.00
Maranhão	7138	4.36
Paraná	5344	3.27
Rondônia	5291	3.23
Santa Catarina	2035	1.24
Acre	1338	0.82
Amazonas	1121	0.69
Roraima	959	0.59
Amapá	353	0.22
Others	17 816	10.89
Brazil	163 562	100

* Percent of total land area used for beef production.
Source: Adapted from New Zealand Trades and Enterprise (2010).

enterprises' raise fewer than 500 head per household per year. The medium specialised beef operations on average produce over 1000 head annually. The last category, commercialised beef production enterprises, produce over 4000 head each year (Somwaru and Valdes 2004).

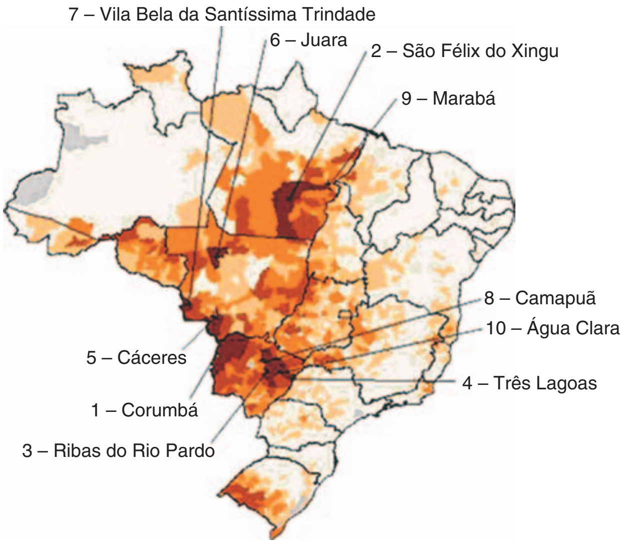


Figure 6.3: The most important Brazilian states in terms of cattle population. The darker the colour the greater density of cattle. Source: Adapted from IBGE (2006).

Production systems can also be classified by the type of activity performed, such as cattle breeding, cattle raising and cattle fattening (Chapter 4). Breeders produce calves; cattle raisers buy calves and produce two-year-old calves and heifers, and in the cattle fattening business, steers or cows are raised until the slaughter point is reached. Most of the livestock properties in Brazil undertake the complete cycle of breeding, raising and fattening (Table 6.2).

Since different environments are found in different regions (National Institute for Space Research – INPE; http://www.inpe.br/ingles), the beef cattle production systems also differ from one region to another to adapt the best system to the local biome. Throughout the different locations of beef cattle production, most soils are acidic, presenting medium to low fertility and supporting important grass species like *Brachiaria* spp. and *Panicum* spp. (originally from Africa). These grass species were introduced into Brazil in the late 1960s and early 1970s and led to improved varieties that were better adapted to different types of soil and environments. These are now widely used by beef producers.

With regard to sown grass diversity, Brazil has ~100 million ha of cultivated pastures and eight grass and 7 legume genera, with a total of 20 species registered for seed production at the Ministry of Agriculture, Livestock and Supply (Euclides *et al.* 2010). Data from the forage seed market in Brazil indicates that 45% of the area and 60% of the seed production is of *Brachiaria brizantha* cv. Marandu and 90% of the seed exported is of four *Brachiaria* cultivars (Euclides *et al.* 2010).

Table 6.2: Properties undertaking each kind of livestock activity, selected states (%)

State	Breeding	Rearing	Cattle fattening	Complete cycle
Minas Gerais	25.9	19.8	11.7	42.6
Goiás	36.0	16.2	6.6	41.2
São Paulo	18.2	12.5	16.7	52.6
Paraná	21.1	13.0	20.3	45.6
Santa Catarina	21.2	7.7	19.0	52.1
Rio Grande do Sul	20.7	6.3	3.2	69.9

Source: Adapted from New Zealand Trades and Enterprise (2010).

In grass-fed systems, mineral supplementation is required throughout the year as the majority of the soil in cattle regions is very low in minerals, mainly phosphorus, calcium and almost all the trace minerals (Tokarnia et al. 2000). Mineral supplementation is required to avoid decreases in animal performance due to distribution and seasonal variation in quantity and quality of forage in the tropical environments. Additionally, strategies to improve calf weight gain even during the suckling period are commonly used. Creep-feeding is the most common strategy used in grazing systems in Brazil to increase cattle weight at weaning and consequently reduce the raising period (Valente *et al.* 2012). It consists of a supplementation strategy based on feeding calves *ad libitum* with a balanced ration (usually composed of 17–18% crude protein and 75–80% total digestible nutrients) from feed bunks which only calves can access. Milk production in beef females typically peaks about two months after calving and it offers only about half the nutrients that a three- to four- month-old calf needs for maximum growth. Thus, supplementation of nursing beef calves can provide extra nutrients for calves to better meet their genetic potential (Chapter 18).

Ranches that supplement calves during the pre-weaning period (i.e. creep-feeding) produce heavier weaned animals, which in turn will need a shorter period of time in the feedlot during the finishing phase. These animals may go directly to one of the three following finishing schemes (Ferraz and Felício 2010):

- ‘super early-maturing’ system, where calves are weaned and sent to feedlots at eight months of age and 240 kg bodyweight. The animals stay at the feedlot for 120 days, and are slaughtered at 420 kg liveweight;
- ‘early-maturing’ system, where calves are weaned at ~170–190 kg (seven to eight months old) and are reared in grazing systems until 18–24 months old and then sent to regular feedlots, weighing around 350 kg BW;
- ‘pasture growing system’, where animals are kept on variable quality pastures and harvested at an age of 30–42 months, with liveweight between 450 and 500 kg.

The use of feedlots has increased in Brazil (Millen *et al.* 2011) because, among other reasons, the rate of weight gain is greater with concentrate than with forage-based diets, reducing the time that cattle need to be fed. Consequently this lowers the cost of interest on the capital invested in animals (Duarte *et al.* 2011a), as they will stay for a shorter period of time in the ranch. The production cycle conducted exclusively with grazing systems using mineral supplementation leads to older animals at market and poorer meat-eating quality (Millen *et al.* 2011). Beef quality is greatly influenced by age of the cattle at slaughter, mainly due to greater collagen deposition and the reduction on its solubility, which leads to a tougher meat (Duarte *et al.* 2011a).

The beef feedlot industry in Brazil has consolidated in the last decade as an option for finishing cattle because of the increasing demand from export markets. The number of animals finished in feedlots in Brazil increased 50% (from 1.5 to 3 million animals) during the 2000s (ABIEC 2011), with most beef produced in Brazilian feedlots destined for external markets. Even though feedlots represent only a small proportion of the beef systems in Brazil, they are seen by beef producers as an emerging trend. Confirming the trend and despite the higher grain prices throughout 2012, cattle on feed increased 17% year-on-year to 4 million head (ABIEC 2011), representing 2% of the total herd.

Regarding the breeds used in the beef systems in Brazil, according to the Zebu Breeders Association of Brazil, 75–80% of the Brazilian herd has *Bos indicus* content. The beef breed with the largest number of animals in Brazil is Nellore (standard/horned and polled), followed by Guzera and Gyr, all of them *Bos indicus* breeds originating from India (Fries and Ferraz 2006). Brazil has become the largest breeder of Nellore and from there the breed was exported to Argentina, Paraguay, Venezuela, Central America, Mexico, the USA and other countries (Mason 1988).

The main advantage of the Nellore breed over other breeds of beef cattle is its hardiness. Nellore cattle, as other *Bos indicus* breeds, can withstand hot and humid weather, tolerate intense sunshine, resist parasites and utilise poor-quality forages (Turner 1980). The ability of Zebu breeds to adapt to the climatic conditions that prevail in the tropical zone, as well as their moderate growth capacity and resistance to ectoparasite infestations, favours their use in extensive production systems under tropical conditions (Cundiff 2005).

Crossbreeding is used in all regions of the country, but the higher the percentage of *Bos taurus* contribution, the poorer the adaptability to the tropical environment, often seen in lower resistance to ectoparasites and lower reproductive performance (Chapter 14). The major *Bos taurus* breeds used in beef crossbreeding are Angus and Red Angus, Simmental, Charolais, Polled Hereford, Limousin, Braunvieh and Marchigiana. Synthetic breeds, such as Brangus, Braford, Canchin/Charbray and Santa

Gertrudis, are also used. In the last decade there has been interest from cattle producers in *Bos taurus* breeds adapted to a tropical environment, e.g. Brazilian Caracu, Senepol, Tuli and Bonsmara, and in composite breeding programs (Fries and Ferraz 2006; Chapter 17). The southern region of Brazil is recognised as an area of lower temperatures and fertile soil types with higher nutritional levels which allows the *Bos taurus* (European breeds) to adapt well. This region is the home of the major European cattle herd with Aberdeen Angus, Red Angus Hereford the main breeds (ABIEC 2011).

As stated previously, Nellore is the main breed used in Brazilian beef systems due to their adaptability to the tropical environment. However, among *Bos indicus* cattle Nellore cattle have lower production, due to lower levels of milk production and compromised carcass traits compared to *Bos taurus* breeds (Sartori *et al*. 2010). It has also been shown that *Bos indicus* cows, specifically Nellore, have a long post partum anestrous interval in comparison to *Bos taurus* females, which has contributed to lower reproductive efficiency over time (Sá Filho and Vasconcelos 2010). To address this issue, Brazilian beef producers have incorporated crossbreeding of *Bos indicus* and *Bos taurus* cattle, to obtain the environmental adaptation of *Bos indicus* cattle and the higher production of *Bos taurus* cattle, along with the benefit of hybrid vigour (Sartori *et al*. 2010). Most crosses are utilising Angus genetics as the *Bos taurus* component, with the intention of improving the quality of calves (i.e. age to puberty, meat quality and reproductive performance; Pohler et al. 2011). As Brazilian beef production has been increasing rapidly, progress in genetic and animal improvements has been observed mainly through the use of evaluation programs and carefully planned mating systems. These gains in genetics are largely in traits that are obtained relatively easily and at low cost and that are useful for cattle management. They include weight traits such as birth weight, weaning weight, yearling weight and mature cow weight. Additionally, traits related to calving ease, birth dates and breeding dates can form the basis of fertility evaluations. Through large-scale recording programs, genetic improvement supported with genetic evaluation programs has allowed genetic improvement of these traits (Miller 2010). More recently, ultrasound has become a very important source of information regarding carcass traits and it has been extensively used in animal improvement programs.

The use of reproduction technologies has increased in the Brazilian beef production system in the past 10 years. Artificial insemination (AI) is used to breed ~7–12% of the cows nationwide. According to data from the Brazilian Association of Artificial Insemination (ASBIA 2010), there has been nearly a 40% increase in the volume of beef semen marketed in Brazil in the last decade. The overall growth of semen sales for both beef and dairy clearly points out the rapid adoption of AI in both industries. In 2010, ASBIA estimated that 6.1 million units of beef semen were used in AI programs in Brazil. Drovers Cattle Network estimates that Brazil imports ~5 million units of semen from the USA each year, with most being Angus. This demonstrates the emphasis placed on crossing *Bos indicus* and *Bos taurus* breeds to incorporate into *Bos indicus* cows the traits from *Bos taurus* that they lack, while at the same time conserving the heat tolerance and disease resistance characteristics of *Bos indicus* cattle (Pohler *et al*. 2011).

In addition to AI, the use of ultrasound for pregnancy diagnosis has been intensively used by beef producers in Brazil. It is estimated that ultrasound is used to determine pregnancy in 15–20% of the total cow herd in Brazil (ASBIA 2010). That percentage overlaps with the percentage of cows on AI programs in Brazil, which is around 7–12%. This can be attributed to the increased use of resynch protocols which are becoming very common for diagnosing pregnancy, in order to resynchronise cattle due to the long anestrus period in *Bos indicus* cows.

Transfer of *in vitro* and *in vivo* produced embryos has been extensively used in Brazil. Brazil accounts for 9.3% of the total global supply of *in vivo* produced embryos and 66% of the total *in vitro* embryo production, which collectively accounts for ~30% of total embryo production worldwide (Pohler *et al*. 2011). Because of the greater antral follicle population in *Bos indicus* cattle in relation to *Bos taurus* cattle, *in vitro* embryo production has been much more successful in *Bos indicus* breeds (Viana and Camargo 2007).

COW–CALF SECTOR

The cow–calf phase in Brazil occurs predominantly in extensive grazing systems with native and/or cultivated pastures. Brazilian calf production increased 9.5% during the 2000s from 44.3 to 47.5 million animals (ABIEC 2011). Because of the foot and mouth disease outbreak in 2005, a large number of cows were slaughtered in 2005 and 2006 and many ranchers left the industry. As a result, calf production decreased in 2006 and 2007; however, in 2008 the number of calves produced returned to the level achieved before the outbreak of foot and mouth disease, as more females were retained by ranchers (Millen *et al.* 2011).

Adoption of technologies that increase the number of calves produced per year and their bodyweight at weaning are mandatory in the cow–calf sector (Chapter 14). The main technologies used by ranchers to have an efficient sector producing heavy and healthy calves are:

- strategic feed management of dams during the breeding season as well as at the pre- and post-natal phases;
- grazing management to segregate different classes of animals into different quality pastures;
- use of creep-feeding to increase calves' bodyweight at weaning and improve reconception of the dams.

Creep-feeding is a supplementation strategy based on feeding calves *ad libitum* with a balanced ration, typically composed of corn, soybean meal and mineral mixture, from feed bunks which only calves can access. This strategy improves the weight gain of the calf, leading to heavier weaned animals, and familiarises the animal to periodic feed supplementation later in its life. From an economic view, creep-feeding is beneficial for producers that raise and finish the animals in a feedlot (retained ownership) since the cattle reach the harvest point in a shorter period compared to animals that have not been supplemented. However, to be efficient, creep-feeding must be synchronised with the breeding season to provide supplement when forage is most limiting. Due to the well-defined dry (May–September) and rainy (October–March) seasons in most areas where main beef production exists, better results from creep-feeding occur when cows are bred in the autumn. In this case, supplementation will be provided to the offspring during the dry season, when pastures are most scarce. However, autumn breeding is limited to very young heifers (16–18 months old) and aims to identify the animals that reached puberty earlier than the average and are able to produce a calf. Other than that, autumn breeding season is not widely used in Brazil. Generally, creep-feeding begins when the calves are around 90 days old, when the milk is not providing all the nutrients required for a high rate of growth.

It has been reported that weight gain efficiency and performance of cattle are to an extent determined during their intrauterine life (Paulino *et al.* 2012). For that reason, maternal nutrition during pregnancy has become a new concern among beef producers in Brazil. Considering that the breeding season in most grazing production systems in Brazil occurs between November and January (Fig. 6.4), pregnant cows usually experience feed restriction during their mid gestation period, which overlaps with the dry season in most of the beef cattle production areas (Duarte *et al.* 2012) (Fig. 6.5).

In order to minimise this problem beef producers have designed different strategies of supplementation for grazing pregnant cows, mainly during the last three months of gestation when most fetal growth occurs (Ferrell *et al.* 1976). However, recent studies have shown that nutrient deficiency from early to mid gestation in ruminant animals can cause reduction of muscle fibre number and muscle mass, consequently affecting

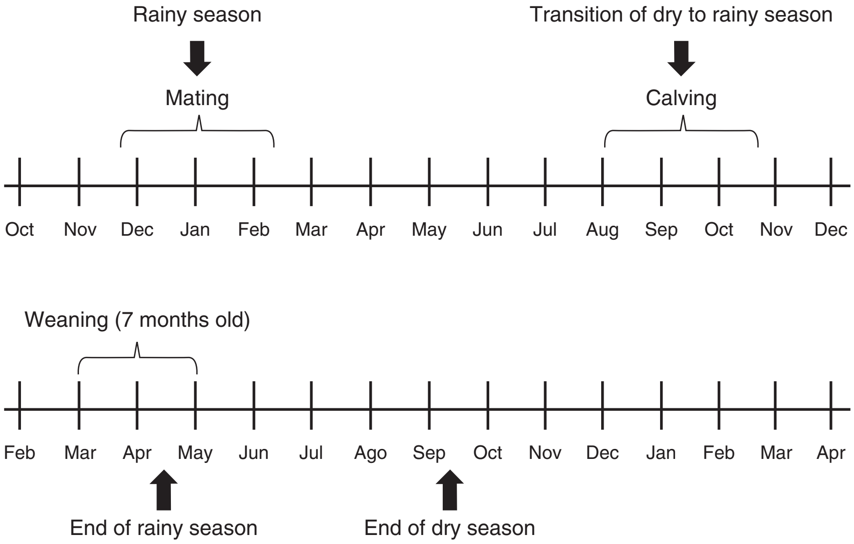


Figure 6.4: Main events of a beef cattle system, according to seasons.

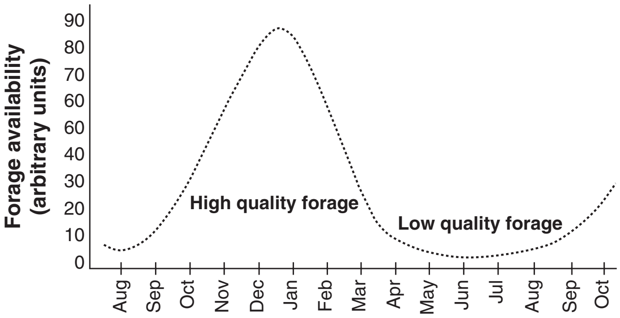


Figure 6.5: Common seasonal variation of quantity and quality of forage in the tropical areas.

performance and the meat quality of progeny (Du *et al.* 2010), even when no difference is observed in the birth weight of the offspring (Wu *et al.* 2006). Calves born from cows that were severely feed restricted during the second and third trimester of pregnancy were 30% lighter than those of high birth weight and remained lighter at all stages of life, up to slaughter at 30 months of age, due to significantly slower rates of gain before and after weaning (Greenwood and Cafe 2007). This suggests that the relatively severe prenatal nutritional restriction may have limited their capacity for later compensatory growth, likely due to a reduction of muscle fibres. As such, in grazing beef systems, maternal undernutrition during gestation seems to be a major problem that might reduce the performance and beef quality traits of progeny. Recent Brazilian research shows that in the near future it will be possible to establish a nutrient supplementation program to ensure proper cow nutrient intake during the critical stages of gestation and thus improve progeny growth efficiency, beef quality and overall profitability (Duarte *et al.* 2012).

STOCKER AND FINISHING OPERATIONS

Stocker operations in Brazil are defined as the phase that goes from weaning (seven to eight months of age) to the beginning of the finishing phase, when the animals reach ~350 kg bodyweight. It can also be defined as the period between weaning (the end of suckling) and the age in which males start the finishing phase and females reach sexual maturity. Stocker operations are a common practice and constitute the greater part of the production cycle, providing a bridge between cow–calf and finishing operations (Millen *et al.* 2011).

The stocker sector in tropical regions typically represents 30–40% of the total Brazilian herd (Mendonça *et al.* 2010) but it represents one of the main problems in the beef chain due to the low growth rates in this period of an animal's life. The lengh of the stocker phase can be up to 24 months with animals not ready for slaughter until at least 36 months of age, leading to a loss in meat eating quality. Strategies to reduce the length of the stocker phase include concentrate supplementation with loose supplements, mostly protein supplements (a mineral

Figure 6.6: Nellore bulls during the finishing phase in a feedlot.

Figure 6.7: Growing Nellore bulls during the stocker phase on tropical pasture during the dry season.

mixture, protein sources like soybean meal, cottonseed meal and some energy source like soybean hulls, citrus pulp, corn or milo) during the dry season (when otherwise they would lose bodyweight) and intensive grazing throughout the year. Intensive grazing system means rotational grazing, when cattle are rotated over several paddocks, where the pasture is fertilised, increasing its production and quality. Greater availability and quality of the pasture is translated into better animal performance and increased growth rate of cattle. The expansion of the feedlot industry allows animals to reach slaughter weights at an earlier age (Figs 6.6–6.8).

Figure 6.8: Intensive grazing of Nellore and crossbred bulls during the stocker phase during the rainy season.

THE FEEDLOT INDUSTRY

The first feedlot in Brazil was built in the early 1970s but only since the 2000s has the industry experienced a great deal of increase in terms of feedlot number and size, and hence overall capacity. On average, ~5–7% of the beef cattle slaughtered in Brazil come out of feedlots. The number of animals in feedlots fluctuates (Fig. 6.9), depending on the availability and price of feeder cattle, grain (mainly corn and soybean) and by-products commonly used in ration formulation in Brazilian diets, including soybean hulls, whole cottonseed, citrus pulp, cottonseed meal and cottonseed cake, peanut meal and corn gluten. Most feedlots take the decision to put cattle on feed based on the market price and the costs after they establish a minimum level of profitability.

Nellore is the main breed used and most of the feedlots feed bulls instead of steers, as steroidal implants are not allowed in Brazil due to restrictions imposed by the European Union, one of the most important importers of Brazilian beef (Chapter 2). Besides that, bulls grow faster, have more efficient feed conversion and produce a leaner carcass than steers.

The feedyards are located around the mid-west, mainly in Goias, Mato Grosso and Mato Grosso do Sul states (a, b and c in Fig 6.10), which, together with Parana and São Paulo, concentrate more than 80% of the cattle fed in feedlots. This is due to the proximity to cow–calf operations, feeder cattle, grain sources and by-products.

In surveys completed in 2009 (Millen *et al.* 2009) and 2010 (Oliveira and Millen 2011), 65–70% of feedlot consultants assisted clients with less than 5000 animals, 13–26% with 5000–10 000 animals and 4–22% attended feedlots with a capacity of greater than 10 000 animals.

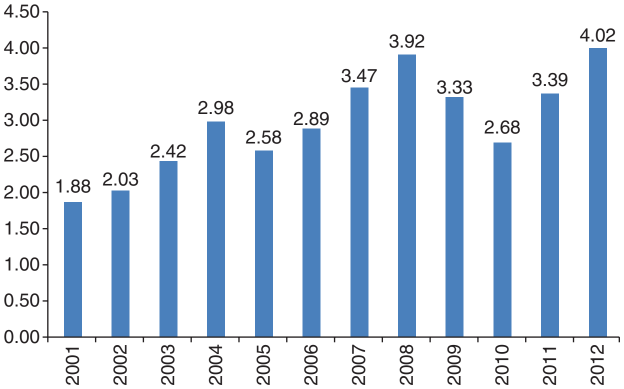


Figure 6.9: Number of animals (million head) in feedlots in Brazil, 2001–12. Source: Adapted from BeefPoint (2012).

Feedlots in Brazil are mostly used as a strategic tool to attain intensification of the production system, as it allows the producer to utilise the tropical pastures close to their maximum potential during the rainy season, then the feedlot during the dry season. The capacity of feedlots in Brazil has increased markedly, with several operations having the capacity to feed over 120 000 animals per year, i.e. finishing three batches of animals (40 000 head capacity at any one time). The diet profile has changed over this period as well. As a feedlot increases in size, it becomes more difficult to produce and handle roughage sources such as corn, sorghum silage and sugarcane, the most important roughages used in Brazil. Thus, the feedlots in Brazil have used larger proportions of concentrate in the diets, as a means of getting better animal performance and lower operational costs. Sugarcane bagasse has become the main fibre source in feedlot diets in Brazil.

Most of the beef cattle production systems in Brazil are pasture based, being influenced by climate, mainly temperature and precipitation, which drives pasture growth. The mid-west region has more than 50% of the Brazilian beef cattle herd, and the breeding season extends from December to March. The objective of ranchers is to match the breeding season with the greatest availability of forage, in order to obtain the best reproductive outcomes (Chapters 15, 18). Precipitation in this region is highest during November to March, decreasing thereafter and reaching almost zero from May to September, the dry season. The weaning season goes from May to August, when most of the calves are weaned and become stockers. After weaning, most of the calves are backgrounded on pasture, receiving protein supplements during the dry season until the rain starts again in October/November. Average daily gain during the dry season can range from 100–500 g, depending on the supplementation strategy. During the rainy season the animals receive only mineral supplementation and have tropical grasses as the main feed source. During this period, the animals can gain around 600–900 g/day. As the rainy season ceases in March/April, the animals are around 20–24 months old. At this point an important decision has to be taken by the rancher. If the animals stay on pasture during their second dry season without any supplementation, they will only become ready to slaughter at the end of the following rainy season when they will be 30–36 months old at slaughter. However, if the rancher adopts protein supplementation the animals can be finished on pasture in a system called semi-confinement, when they have access to

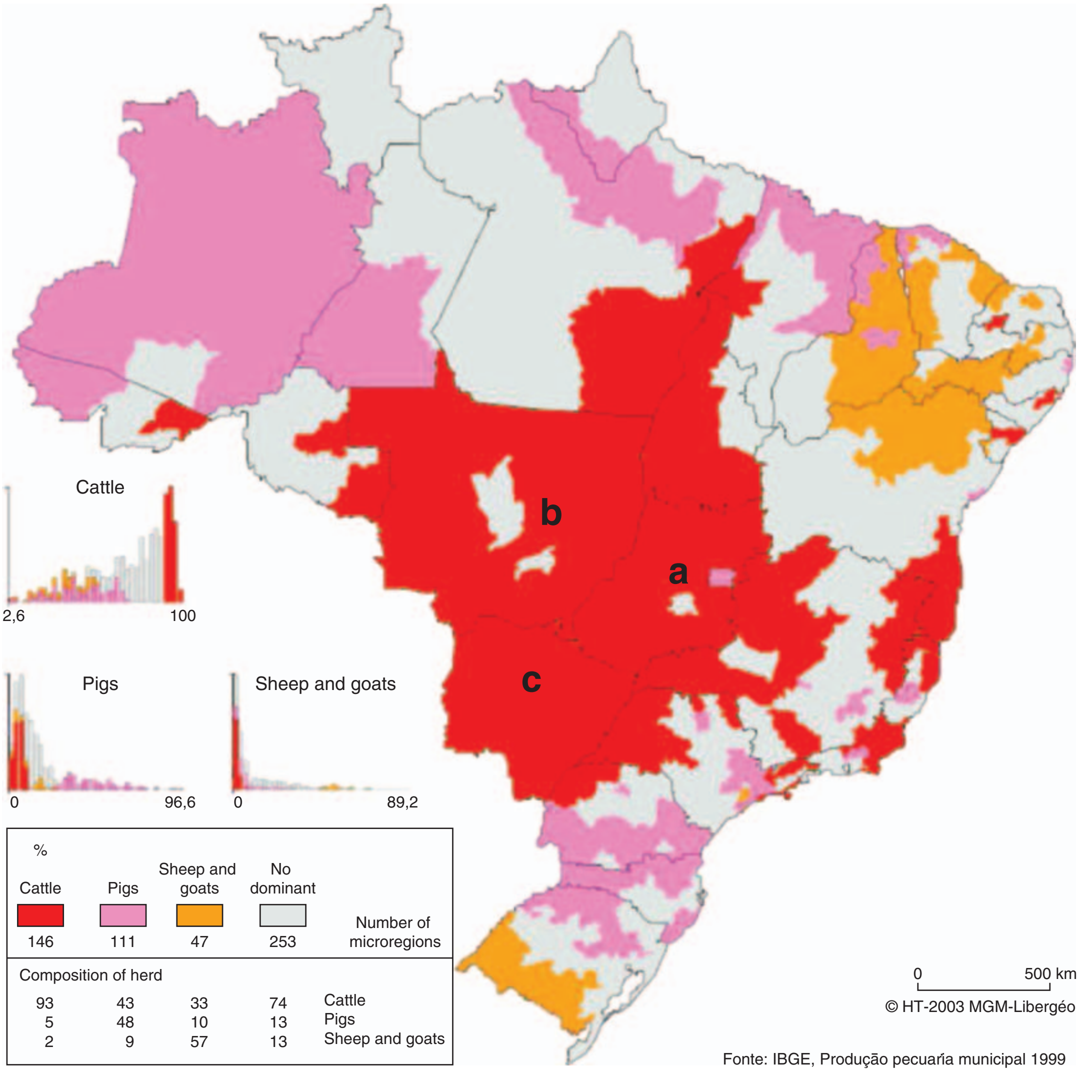


Figure 6.10: The most important states in terms of cattle production (in red). Source: Adapted from IBGE (1999).

a concentrate fed at 1.0% of their bodyweight. In this system, the animals can gain up to 1 kg/day on pasture, during the dry season. In practice, most of the cattle are fed in feedlots during the dry season, when pasture availability and nutritional quality decrease markedly. Typically the animals enter the feedlot weighing around 330–370 kg of bodyweight, and remain on feed for 70–100 days.

PACKING PLANT SECTOR

The Brazilian packing plant sector has experienced a great deal of technological development in recent years and has undergone a very strong process of consolidation and concentration, which began with the global economic crisis of 2008. Currently, three companies dominate the sector, with JBS the largest, followed by Marfrig and Minerva. All have developed different protocols to accomplish the different types of certifications needed to maintain and expand into international markets.

In 2007, there were 14 main beef packing companies operating in Brazil. However, with the 2008–09 global economic crisis, six of them went bankrupt and others were sold to larger companies, due to financial difficulties. In September 2009, Bertin, then the second-largest beef packing plant in Brazil, was bought by JBS, making JBS the most important packing company in the world.

Before September 2009, JBS owned 19 beef plants in Brazil, with slaughter capacity of 18 900 head/day, which represented around 10.08% of the total capacity of all plants in the country (~179 333 animals/day). The second, third, fourth and fifth beef packing plants in that time were Bertin, Marfrig, Independencia and Margen, with slaughter capacity of 14 000 (7.8% of total), 13 550 (7.5%), 10 000 (5.5%) and 8620 (4.8%) heads/day, respectively. In September 2009, JBS ownership of beef packing plants jumped to 37 plants, with a slaughter capacity of 40 000 animals/day, representing 22.3% of the total Brazilian capacity. Marfrig became the second largest, owning 21 plants, with a slaughter capacity of 22 500 head/day (12.5%). The gap between the two big companies and the smaller companies became wider after the process of concentration and consolidation that began in 2008. Currently, the third, fourth and fifth beef packing plants are Minerva, Mataboi and BR Foods, owning six, four and two plants, respectively, with slaughter capacity of 5900, 3500 and 2000 head/day. These numbers represent 3.2%, 1.9% and 1.1% of the total capacity, far below JBS and Marfrig. In some regions, such a Mato Grosso do Sul, the concentration of packing companies reaches even higher levels, i.e. JBS owns more than 70% of the slaughter capacity. The ownership concentration of beef packing plants in Brazil has become a major concern for ranchers due to its influence on the price paid for cattle.

Table 6.3: Brazilian beef production, export and imports, 2009–12

Item	2012	2011	2010	2009
Herd size (million head)	213.6	212.8	209.5	195.6
Slaughter rate (million head)	45.5	42.2	42.8	42.8
Slaughter rate (%)	21.3	19.8	20.44	21.87
Beef production (million tons carcass equivalent)	10.062	9.337	9.507	9.035
Domestic consumption (million tons carcass equivalent)	8.396	7.800	7.748	7.368
Beef consumption per capita (kg/person/year)	42.33	39.67	40.16	38.50
Exports (million tons carcass equivalent)	1.846	1.572	1.797	1.851
Imports (thousand tons carcass equivalent)	56.6	35.6	32.8	33.1

Source: Adapted from Secex/MDIC (2012); IBGE (2012).

DOMESTIC AND INTERNATIONAL MARKETS

Brazil is the largest beef exporter of the world, supplying beef to more than 130 countries. It produced 10 062 million tons of carcass-equivalent of beef in 2012 (Table 6.3), with more than 83% consumed by the domestic market – the most important market for Brazilian beef. Average per capita consumption of beef is 42.3 kg/person. Beef is the most preferred meat in Brazil but its consumption is limited by income.

Brazilian beef exports generated over US$5.7 billion dollars in revenue (in 2012). Russia was the largest importer, followed by Hong Kong, the European Union and Egypt (Fig. 6.11). On average the price of Brazilian beef in the international market was US$4637 ton, ranging from $2952 ton for offals up to $6086 ton of processed beef. Of the beef exported by Brazil in 2012, 76% comprised fresh beef, 14% offals, 9% processed beef and 1% of casings and salted beef (ABIEC 2011).

Brazil still does not export fresh beef to main markets such as Japan, Korea, the USA, Mexico and others, due to foot and mouth disease, which was first discovered in 1895, after being described in Argentina and Uruguay (Lyra and Silva 2004). In the early 1960s the Brazilian government created a national plan to control the disease and, in partnership with the industry, has invested a lot of effort to eradicate the disease. More than 80% of the Brazilian cattle herd (as at 2012) was located in disease-free regions with and without vaccination (Fig. 6.12).

The extreme north and north-east, comprising the states of Amazonas, Amapá, North of Pará, Roraima, Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba,

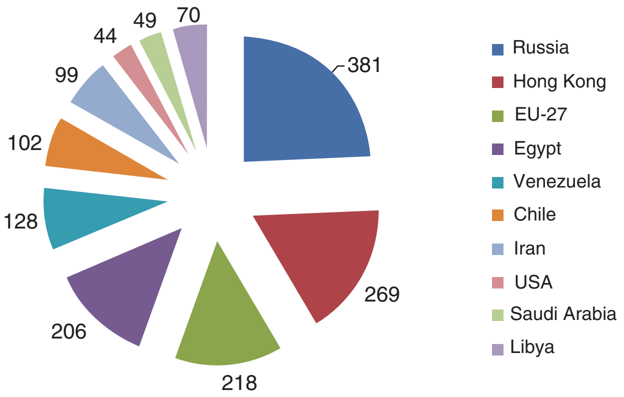


Figure 6.11: Main importers of Brazilian beef in 2012 (million tons carcass equivalent). Source: Adapted from ABIEC (2011).

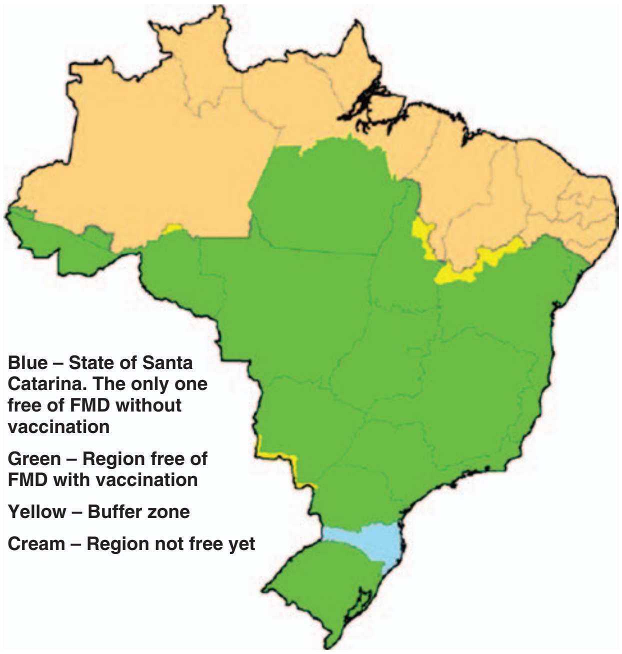


Figure 6.12: Foot and mouth disease in Brazil. Source: Adapted from MAPA (2012).

Pernambuco and Alagoas, are not free of foot and mouth disease due to some difficulties, such as lack of veterinarians, control points on state borders, computer access and so on. It's important to note that beef cattle production is of secondary importance in these states. Also, the Amazon rainforest covers a great part of this area, making it difficult to access remote areas where cattle are reared for subsistence.

The area recognised by OIE as free with vaccination comprises Rio Grande do Sul, Paraná, São Paulo, Rio de Janeiro, Espírito Santo, Bahia, Minas Gerais, Mato Grosso do Sul, Goiás, Distrito Federal, Tocantins, Mato Grosso, South of Pará, Rondônia and Acre.

In conclusion, the beef sector in Brazil has a bright future, as the country has an enormous potential to increase its beef production vertically and by implementing technologies already available to improve productivity. Brazil still has ample land, water resources and relatively cheap labour to use as part of beef production. However, the country is facing a lot of challenges including those related to infrastructure (roads), animal health (foot and mouth disease), animal traceability, supply chain coordination and integration, labour skilling, and extension and rancher education. However, the beef cattle industry in Brazil is still relatively immature and is trying hard to become more professional and organised to address these challenges.

FUTURE DIRECTIONS OF BEEF CATTLE PRODUCTION IN BRAZIL

Beef cattle production in Brazil has faced enormous challenges in recent years, related to environmental regulations, animal welfare, competition for land with more profitable crop production (soybean, corn, sugarcane, eucalyptus) and low economic output. It is estimated that more than 60% of the pasture land in Brazil is going through some level of degradation requiring intervention such as soil correction and fertilisation. Integrated crop–livestock systems have been used extensively in the last decade and the present knowledge indicates that this practice will form the basis of sustainable crop and livestock production in Brazil. Various studies on crop–pasture integration have produced encouraging economic results and its adoption by cattle producers will increase in the near future.

More integration among the various sectors of the beef supply chain is needed to improve the quality of Brazilian beef. The domestic and international markets have become stricter and are demanding more information about the beef they purchase; Brazil has to devise solutions to meet that demand.

An animal traceability system is an important issue yet to be addressed by the Brazilian beef supply chain. In January 2002, the Ministry of Agriculture, Livestock and Supply created the SISBOV – a bovine and buffalo identification and certification system to identify the Brazilian herd and certify production and food-safe conditions. Until 2004, the system was mandatory but after a frustrating result in 2005 the system became voluntary for all producers.

The Brazilian Ministry of Agriculture released projections during 2012 for some agriculture goods including meats. According to the study, beef production will increase at 2.1% per year in the next 10 years, achieving 11.834 million tons. In terms of consumption, the estimate indicated that Brazilian demand for beef will be 9.4 million tons by 2021/22, an increase rate of 2% per year. It also estimated that Brazil will be exporting 1.613 million tons by 2022.

REFERENCES

ABIEC (Associação Brasileiras das Indústrias Exportadoras de Carne Bovina) (Brazilian Association of ANUALPEC) (2011) Anuário da Pecuária Brasileira [Brazilian Annual Livestock Reports]. 1st edn. Instituto FNP/Agra Pesquisas Ltda, São Paulo.

ASBIA (2010) Associação Brasileira de Inseminação Artificial (Brazilian Association of Artificial Insemination).

BeefPoint (2012) Pesquisa Top 50 Beefpoint de Confinamento.

Cundiff LV (2005) Beef cattle: breeds and genetics. In *Encyclopedia of Animal Science*. (Eds WG Pond and AW Bell) p. 74. Marcel Dekker, New York.

Du M, Tong J, Zhao J, Underwood KR, Zhu M, Ford SP, Nathanielz PW (2010) Fetal programming of skeletal muscle development in ruminant animals. *Journal of Animal Science* **88**, E51–E60. doi:10.2527/jas.2009-2311.

Duarte MS, Paulino PVR, Valadares Filho SC, Paulino MF, Detman E, Zervoudakis JT, Monnerat JPIS, Viana GS, Silva LHP, Serão NVL (2011a) Performance and meat quality traits of beef heifers fed with two levels of concentrate and ruminally undegradable protein. *Tropical Animal Health and Production* **43**, 877–886. doi:10.1007/s11250-011-9778-4.

Duarte MS, Paulino PVR, Fonseca MA, Diniz LL, Cavali J, Serao NVL, Gomide LA, Reis SF, Cox RB (2011b) Influence of dental carcass maturity on carcass traits and meat quality of nellore bulls. *Meat Science* **88**, 441–446. doi:10.1016/j.meatsci.2011.01.024.

Duarte MS, Paulino PVR, Du M (2012) Fetal programming in beef cattle: how to optimize performance and carcass value in early life stages. In *Proceedings of the 4th International Symposium on Beef Cattle Production*. pp. 123–140. Viçosa, Brazil.

Euclides VP, Valle CB, Macedo MCM, Almeida RG, Montagner DB, Barbosa RA (2010) Brazilian scientific progress in pasture research during the first decade of XXI century. *Brazilian Journal of Animal Science* **39**, 151–168.

Ferraz JBS, Felício PE (2010) Production systems: an example from Brazil. *Meat Science* **84**, 238–243. doi:10.1016/j.meatsci.2009.06.006.

Ferrell CL, Garrett WN, Hinman N (1976) Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. *Journal of Animal Science* **42**, 1477–1489.

Fries LA, Ferraz JBS (2006) Beef cattle genetic programmes in Brazil. In *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production*. pp. 1–8. Belo Horizonte, Brazil.

Greenwood PL, Cafe LM (2007) Prenatal and pre-weaning growth and nutrition of cattle: long-term consequences for beef production. *Animal* **1**, 1283–1296. doi:10.1017/S175173110700050X.

IBGE (1999) *Produção da Pecuária Municipal*, vol. 27. Instituto Brasileiro de Geografia e Estatística.

IBGE (2006) *Produção da Pecuária Municipal*, vol. 34. Instituto Brasileiro de Geografia e Estatística.

IBGE (2012) *Indicadores IBGE: Estatística da Produção Pecuária*. Instituto Brasileiro de Geografia e Estatística.

Lyra TMP, Silva JA (2004) The foot-and-mouth disease in Brazil, 1960–2002. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* **56**, 565–576. doi:10.1590/S0102-0935200 4000500001.

MAPA (2012) *Evolução Geográfica do Processo de Implantação de Zona Livre de Febre Aftosa no Brasil*. Ministério da Agricultura, Pecuária e Abastecimento. <http://www.agricultura.gov.br/arq_editor/file/Evolucao_z_livre_mai2012.pdf>.

Mason IL (1988) *World Dictionary of Livestock Breeds*. 3rd edn. CAB International.

Mendonça BPC, Lana RP, Mancio AB, Detmann E, Barbosa AM, Guimarães G (2010) Levels of mineral mixture and urea in supplementation of crossbred heifers, with Gir predominance, reared at pasture during the dry season. *Brazilian Journal of Animal Science* **10**, 2273–2280.

Millen DD, Pacheco RDL, Arrigoni MDB, Galyean ML, Vasconcelos JT (2009) A snapshot of management practices and nutritional recommendations used by feedlot nutritionists in Brazil. *Journal of Animal Science* **87**, 3427–3439. doi:10.2527/jas.2009-1880.

Millen DM, Pacheco RDL, Meyer PM, Rodrigues MHM, Arrigoni MDB (2011) Current outlook and future perspectives of beef production in Brazil. *Animal Frontiers* **1**, 46–52. doi:10.2527/af.2011-0017.

Miller S (2010) Genetic improvement of beef cattle through opportunities in genomics. *Brazilian Journal of Animal Science* **39**, 247–255.

New Zealand Trades and Enterprise (2010) *Beef Market in Brazil: Market Profile*. <http://www.nzte.govt.nz>.

Oiagen RP (2010) Evaluation of competitiveness in the beef cattle production systems in the southern and northern of Brazil. PhD thesis. Agronomy Department, Federal University of Porto Alegre, Brazil.

Oliveira C, Millen DD (2011) Survey of nutritional recommendations and management practices used by Brazilian feedlot consulting nutritionists: general information and adaptation. In *Proceedings of the 48th Annual Meeting of Brazilian Animal Science Society*. Belém, Brazil.

Paulino PVR, Duarte MS, Gionbelli MP (2012) Desempenho e eficiência de ganho: tudo começa antes do que você imagina [Performance and gain efficiency: everything begins before we imagine]. *Encontro de Confinamento da Scot Consultoria*. pp. 37–56. Ribeirão Preto, Brazil.

Pereira PAA, Martha Junior GB, Santana CAM, Alves E (2012) The development of Brazilian agriculture: future technological challenges and opportunities. *Agriculture and Food Security* **1**, 4 doi:10.1186/2048-7010-1-4.

Pohler KG, Mallory DA, Patterson DJ, Smith MF, Lauderdale JW, Martins T, Peres RFG, Vilela ER, Vasconcelos JLM (2011) Reproductive technology and global production of beef: why beef producers in the U.S. need to pay attention. In *Proceedings of Applied Reproductive Strategies in Beef Cattle*, 31 August–1 September. Joplin, Mo.

Sá Filho OG, Vasconcelos JLM (2010) Treatments to optimize the use of artificial insemination and reproductive efficiency in beef cattle under tropical environments. *Veterinary Medicine International*.

Sampaio CB, Detmann E, Paulino MP, Valadares Filho SC, Souza MA, Lazzarini I, Paulino PVR, Queiroz AC (2010) Intake and digestibility in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. *Tropical Animal Health and Production* **42**, 1471–1479. doi:10.1007/s11250-010-9581-7.

Sartori RMB, Baruselli PS, Gimenes LU, Ereno RL, Barros CM (2010) Physiological differences and implications to reproductive management of *Bos taurus* and *Bos indicus* cattle in a tropical environment. In *Reproduction in Domestic Ruminants VII*. (Eds MC Lucy, JL Pate, MF Smith and TE Spencer). Nottingham University Press, Nottingham.

Secex/MDIC (2012) Secretaria de Comércio Exterior/Ministério do Desenvolvimento, Indústria e Comércio Exterior Exportações de Commodities.

Somwaru A, Valdes C (2004) Brazil's beef production and its efficiency: a comparative study of scale economies. In *GTAP 7th Annual Conference on Global Economic Analysis*. pp. 1–19. Washington DC.

Tokarnia CH, Döbereiner J, Peixoto PV (2000) Deficiências minerais em animais de fazenda principalmente bovinos em regime de campo. *Pesquisa Veterinaria Brasileira* **20**, 127–138.

Torres AM Jr, Neto HPD (2012) Rápido e silencioso avanço da cadeia da carne bovina [Rapid increase of Brazilian beef chain]. *Encontro de Confinamento da Scot Consultoria*. pp. 9–16. Ribeirão Preto, Brazil.

Turner JW (1980) Genetic and biological aspects of Zebu adaptability. *Journal of Animal Science* **50**, 1201–1205.

Underwood KR, Tong JF, Price PL, Roberts AJ, Grings EE, Hess BW, Means WJ, Du M (2010) Nutrition during mid to late 459 gestation affects growth, adipose tissue deposition, and tenderness in cross-bred 460 beef steers. *Meat Science* **86**, 588–593. doi:10.1016/j.meatsci.2010.04.008.

Valente EEL, Paulino MF, Detmann E, Valadares Filho SC, Barros LV, Cabral CHA, Silva AG, Duarte MS (2012) Strategies of supplementation of female suckling calves and nutrition parameters of beef cows on tropical pastures. *Tropical Animal Health and Production* **44**, 1803–1811. doi:10.1007/s11250-012-0142-0.

Viana JHM, Camargo LSA (2007) Bovine embryo production in Brazil: a new scenario. *Acta scientiae Veterinariae* **35**, 920–924.

Wu G, Bazer FW, Wallace JM, Spencer TE (2006) Intrauterine growth retardation: implications for the animal sciences. *Journal of Animal Science* **84**, 2316–2337. doi:10.2527/jas.2006-156.

7 Chinese and South-East Asian cattle production

S.A. Waldron and C.G. Brown

CHINA AND SOUTH-EAST ASIA

Background

Beef cattle production systems described in this chapter are extremely diverse, ranging from transhumant pastoralism in Xinjiang, to feedlots that feed imported Brahmans on plantation crops in Sumatra. However, the majority of cattle in China and South-East Asia are produced in smallholder crop–livestock systems, where cattle bred over millennia for draught purposes are fed on crop residues and other low-grade feeds, are kept as a form of 'savings' to meet immediate household needs, and are sold into rudimentary cattle marketing, processing and beef retail systems.

The dominant supply chains in China and South-East Asia are therefore undeveloped compared to other regions covered in this book. The beef industries are, however, as dynamic as the regions in which they are located. Farm mechanisation is displacing draught animals, households make and save money through means other than cattle, and are increasingly integrated into markets. Rapid economic growth, industrialisation and urbanisation in much of the region provide incentives for small cattle producers to either leave the cattle production sector or to become more commercialised. Thus, semi-subsistence households operate alongside or even supply into fully-fledged commercial beef systems.

The development paths that Asian beef industries take have wide-ranging implications. China is the third-biggest beef producer in the world, only marginally behind Brazil (Chapter 6), and produces three times more beef than Australia. Indonesia is a mid-sized producer ranked 27th in the world but the largest in South-East Asia, with a large import sector for both live cattle and beef. What happens in these countries impacts on trade partners and world cattle and beef markets. Of primary concern to domestic policy-makers in the region, industry development affects a very large number of domestic producers and consumers, with implications for food security, rural development, food safety and the environment.

The scale and dynamics of industry development in the region pose major questions for business, government and research. Will the beef industries of developing Asian countries grow or contract? What will be the industry development trajectories, and will they necessarily mirror that of more developed beef industries? Will beef consumption levels and patterns become more westernised? What trade patterns might emerge from this alignment of factors?

To provide a base from which to assess likely future developments, this chapter takes a long-term, historical, 'big picture' perspective of the development of the Chinese and Indonesian industries. It does so mainly through the presentation of statistical information. While macro statistics can be imprecise, they can be critically examined to provide invaluable context on industry development trends. The section below draws on FAOStat statistics commonly used in English-language studies, but the country sections draw on national statistics that can differ from FAOStat data and are more disaggregated, difficult to source and interpret. Use of official country data is particularly useful in communicating with policy-makers in the region who draw on the same datasets. In the case of China, the statistics have been cross-verified with data collected on prolonged fieldwork, project collaboration, trials, modelling and publications including Waldron (2010), Waldron *et al*. (2007, 2003), Brown *et al*. (2002) and Longworth *et al*. (2001). The Indonesia section is based on statistical analysis and a detailed industry and value chain analysis (Waldron *et al.* 2013).

This chapter concentrates on two countries, China and Indonesia. Economic liberalisation during the 1980s and interventionist policy in the 1990s led to a rapid expansion of the Chinese beef industry. However, in the 2000s many farmers left cattle production to take up opportunities in other booming sectors of the economy, leaving a smaller but more commercialised industry with some interesting Chinese characteristics. There are strong parallels between the beef industries of China and Indonesia, although the Chinese industry has undergone more pronounced change due to rapid development of the broader economy while the Indonesian industry is more directly exposed to international markets. China may provide lessons – both positive and negative – for the Indonesian industry, especially as government attention to the Indonesian industry has intensified in recent years. The story of the development of the beef industries in China and Indonesia will be of interest to the stakeholders of other developing Asian beef industries, and of other more developed industries that operate in Asia (e.g. the USA, Brazil, Australia).

China and Indonesia in context

Statistics in Table 7.1 provide a long-term overview of the cattle and beef industries of the world, China, South-East Asia and Indonesia. In order to maintain consistency in comparing these regions, data is drawn from a single source – FAOStat. Data on buffaloes and buffalo meat is not included.

China is a major beef producer and Indonesia a mid-sized producer in international context. Growth rates for beef production in China, South-East Asia and Indonesia over the last two decades (Row D) are high by world standards. This is due not to a rapid increase in cattle numbers (Row A) but to increased turnoff or slaughter rates (C). After major fluctuations – both real and statistical – over the last two decades, cattle numbers in China are now back to 1991 levels. Growth in cattle numbers in Indonesia are modest, but are above world averages and were found to be understated in the 2010 bovine census (see below).

There has been a very high increase in the growth in turnoff for China over the 1991–2010 period (8.6%; Row B) with a much lower growth in turnoff for Indonesia (1.9%). In interpreting these figures, it is important to note that in China they refer to the exchange of animals (turnoff), which can happen several times before an animal is slaughtered. Even so, the high growth in turnoff numbers is an important indicator of industry commercialisation.

While figures in Row B refer to turnoff in China, the Indonesian figures relate to slaughter numbers. Furthermore, the Indonesian slaughter figures are understated. Figures reported in FAOStat are 12% below those reported by the (Indonesian) Directorate General of Livestock and Animal Health (see Indonesia section below), which themselves are understated because they don't record illegal slaughtering.

Table 7.1: Key cattle and beef indicators from the world, China, South-East Asia and Indonesia, 1991–2010

Row	Statistical item	World	China	SE Asia	Indonesia
A	Cattle herd (million head 2010)	1429	84	48	14
	Average annual growth 1991–2010 (%)	0.5	0.2	1.6	1.3
B	Turnoff or slaughter (million head 2010)	296	44	7	2
	Average annual growth 1991–2010 (%)	0.8	8.6	2.8	1.9
C	Turnoff/slaughter rates (% 2010) (B/A)	21	53	14	13
	Average annual growth 1991–2010 (%)	0.3	8.4	1.2	0.6
D	Cattle meat (million tonnes 2010)	62.3	6.2	1.3	0.4
	Average annual growth 1991–2010 (%)	0.8	8.2	3.3	3
E	Average carcass weight (kg/head 2010) (D/C)	211	141	167	232
	Average annual growth 1991–2010 (%)	0	–0.4	0.8	0.6
F	Cattle meat supply (kg/person 2007)	9.6	4.7	4.2	1.9
	Average annual growth 1988–2007 (%)	–0.4	9.2	–0.3	0.9
G	Producer price cattle meat (US$/kg 2009)	4.2	4.2	3.0	5.4
	Average annual growth 1991–2009 (%)	1.2	8.1	0.9	2.5

Source: Adapted from FAOStat (2012).

The high and growing turnoff rate for China (53%) reflects its vibrant cow–calf, fattening and trading sectors. Cow–calf producers have relatively high conception, calving and survival rates; cattle are turned off at an early age and swap hands through increasingly specialised speculative fattening households and traders before slaughter. This system seen in most of China approximates that of smallholder cattle systems in lowland parts of Java. However, for Indonesia as a whole, the low reported slaughter rate (13%) reflects uncommercialised systems, with low productivity indicators, where cattle are kept as a source of 'savings' with low weight gains for long periods before being slaughtered.

Growth in beef production (Row D) has increased rapidly in China over the 1991–2000 period (8.2%). The growth stems from higher turnoff rates, but not from increased carcass weights (Row E, derived by dividing Row B by Row D), which are low (141 kg) and declining. While these carcass weights may be understated (due to turnoff numbers being equated with slaughter numbers), they are not dissimilar to the weights of carcasses seen in slaughterhouses and markets throughout China. Producers have incentives to sell cattle at a young age or light weight to avoid feed costs in low-growth systems.

Indonesian cattle are heavier than Chinese cattle (Row E). However, the average carcass weight for Indonesian slaughter cattle reported by FAO (232 kg) is clearly overstated, for two reasons. First, it includes imported cattle (Chapter 12) which in 2010 totalled 521 000 head (up to a quarter of the total slaughter number) and are relatively heavy (notionally 350 kg liveweight imported plus additional fattening in Indonesia). Second, the heavy carcass weights are a result of dividing beef output (D) by understated slaughter numbers (B).

The increase in productivity in much of the country has seen China increase per capita beef supply by more than 9% per year over the 1991–2000 period (Row F). Per capita supply is still half the world average, although beef is a minor source of meat protein in the Chinese diet compared to pork. This is not the case in the predominantly Muslim country of Indonesia, making the low per capita supply of beef (1.9 kg) more pronounced. As a result, prices for cattle and beef are very high in Indonesia. Beef prices have increased rapidly in China, especially in recent years, to approach world levels.

CHINA

Like the broader economy, China has a large and rapidly changing beef industry. The production and policy drivers that underpin this change are summarised in Fig. 7.1. Note that Chinese official statistics used in this section

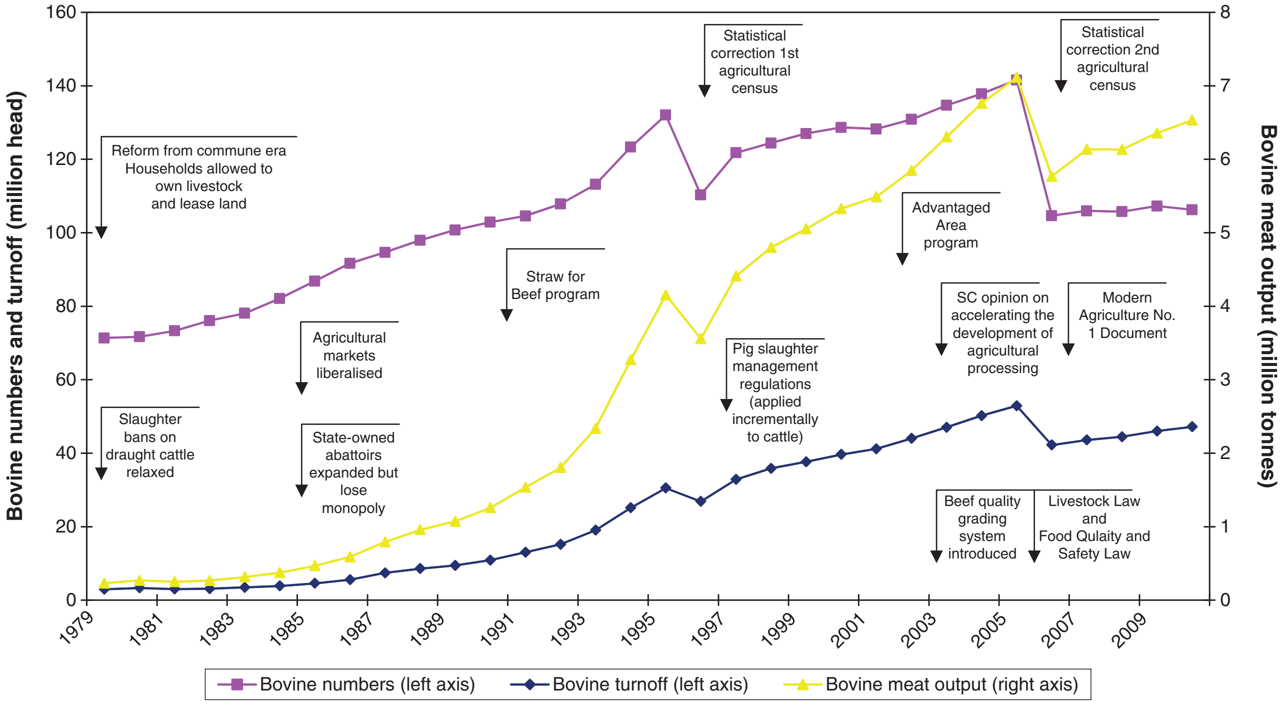


Figure 7.1: Production trends and policies in the Chinese beef industry, 1979–2010. Source: China Livestock Yearbook (various years) and authors.

differ in some cases from those of the FAO presented above. Bovine numbers and meat include beef cattle, buffaloes and yaks.

Policy and statistics

In the pre-1979 central planning era, China had a large cattle herd. Cattle were owned by communes for draught purposes in agricultural areas and there were bans on the slaughter of productive animals; only sick or injured animals were available for consumption. However, cattle were raised in larger herds in extensive pastoral systems in western China (e.g. Inner Mongolia) to produce beef for ethnic minority populations and cities in northern China.

Economic reforms of the 1980s – where households were able to lease land and own and sell animals – released pent-up resources and incentives. Households responded by raising cattle for their own draught purposes in small-scale crop–livestock systems (average of 1 ha per household) and to periodically generate cash income.

Whereas growth was facilitated by liberalisation measures of the 1980s, it was driven by proactive industry policy in the 1990s. In particular, the 'Straw of Beef' program was introduced to utilise China's 500 million t of crop residues (especially straw) as feed for cattle (Waldron *et al*. 2003). The program aimed to increase the incomes of farmers (by raising cattle), increase food supply for China (produce beef without displacing grain for human consumption) and bring environmental benefits (less burning of straw, more manure). Notwithstanding the low efficiency of conversion by which straw – even if ammoniated or ensiled – is converted into beef, the program was implemented across vast areas of China and millions of households.

Caught up in the fervour of the Straw for Beef program, and to increase their chances of promotion, local officials reported inflated output figures. In China's 'bottom-up' statistical collection system, this fed up into inflated national level statistics. The extent of the overreporting was revealed in the First National Agricultural Census, conducted in 1997, when survey teams descended on villages to independently collect data. In the wake of the census, cattle numbers were revised downward by 16.5%, turnoff by 28% and beef by 23%. The census figures were then used to retrospectively revise statistics for the preceding three years.

The revisions made policy-makers, business and researchers increasingly wary of production indicators that again trended sharply upward in the 2000s. Suspicions were confirmed in the Second National Agricultural Census of 2007, which revealed even higher overstatement of 26% for cattle numbers, 20% for turnoff and 19% for beef. There are important implications for assessment of the international livestock sector, especially as the 'international livestock revolution' (Delgado *et al*. 1999) was premised to a very large extent on inflated growth figures from China.

One of the trends that emerge from (post-census) data (Fig. 7.1) is the declining bovine stock numbers, which by 2010 were back at around the levels of 1990. In addition to statistical anomalies, the declines are also real. This is because agricultural households that had entered the industry in the 1990s left in the 2000s, and because farm mechanisation reduced the need for draught cattle. The number of draught animals (of all types) in China dropped from 71 million in 2002 to 43 million in 2009 (China Livestock Yearbook 2010). Interrelatedly, farmers are migrating to cities in droves. While 74% of China's population lived in rural areas in 1990, only 50% did in 2010 (NBS 2011). Most working-age farmers in eastern and central China have access to off-farm work in other sectors of China's burgeoning economy. Becoming increasingly conscious of the (opportunity) cost of their labour, households increasingly value the time they put into livestock production, which makes cattle production in small-scale systems unviable (Longworth *et al*. 2001; Waldron 2010). Two million households (one-seventh of all cattle holding households) exited the cattle production sector between 2003 and 2009 (China Livestock Yearbook, various years).

However, the 14 million households that still raised cattle in 2010 are becoming increasingly commercialised. Although bovine numbers have declined, bovine turnoff increased by an average of 7% per year between 1991 and 2010. This is reflected in turnoff rates that increased from 11% to 44%. Beef production also increased by an average of 8% per year over in the period. The higher rate of growth (compared to turnoff) is due to increased beef yields (carcass weights, bone-in). However, average carcass weights in China are still low (138 kg) and actually declined over the 2000s. That is, over the last decade, producers have increased calving and survival rates and responded to economic incentives to turn cattle off at younger ages and lighter weights for slaughter or for fattening in more efficient households or feedlots.

Developments in the production sector resemble those in downstream sectors. Industry expansion in the 1980 and 1990s was accompanied by the proliferation of vast numbers of cattle markets, traders, brokers, slaughterhouses, by-product traders, wet markets and beef retailers. These small-scale, low-cost, 'fragmented' structures are operationally efficient in what is largely a low-value, generic cattle and beef industry. However, especially over the 2000s, Chinese policy-makers and business have turned their attention to the development of industry structures thought to be more suited to meeting value-adding, food safety and trade objectives. These are reflected in some of the key policy measures implemented in the 2000s, including slaughter regulations (to ban backyard slaughtering), the development of larger-scale slaughter and processing companies, new grading systems and food safety regulations.

Regional distribution and change

While the data and policy discussion above illustrates trends at a national level, the Chinese cattle and beef industry is spatially diverse. Some of this diversity is captured by disaggregating the industry into beef zones (Fig. 7.2) and examining the density of cattle distributed by five zones and 25 provinces. Bovine numbers are distributed evenly over the provinces in the map (Fig. 7.2), whereas in reality they are usually concentrated in particular pockets in the province and are subject to change (Fig. 7.3).

South-west provinces are Guizhou (GZ), Sichuan (SC), Guangxi (GX), Yunnan (YN), Jiangxi (JX), Hunan (HuN) and Chongqing (CQ). Other provinces are Shanghai (SH), Guangdong (GD), Hainan (HaN), Zhejiang (ZJ) and Fujian (FJ). Western provinces are Tibet (XZ), Qinghai (QH), Gansu (GS), Inner Mongolia (IM), Ningxia (NX) and Xinjiang (XJ). Central Plains systems provinces are Hubei (HuB), Henan (HeN), Anhui (AH), Shandong (s.d.), Jiangsu (JS), Shanxi (SX), Hebei (HeB) and Shaanxi (ShX). North-east provinces are Jilin (JL), Liaoning (LN) and Heilongjiang (HLJ).

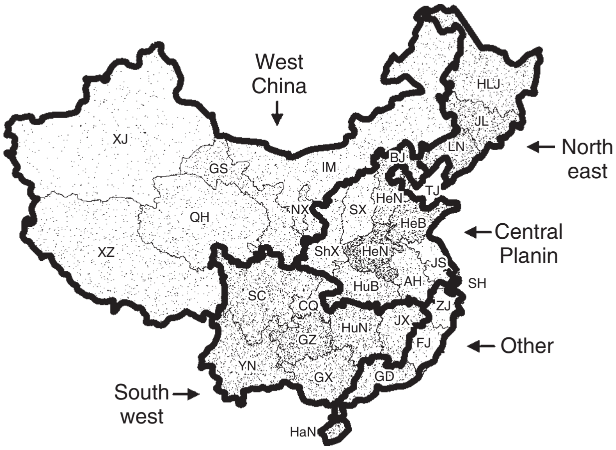


Figure 7.2: 2010 bovine distribution by province in China. One dot equals 200 000 cattle. Source: Map generated by authors. Data from China Livestock Yearbook (2011).

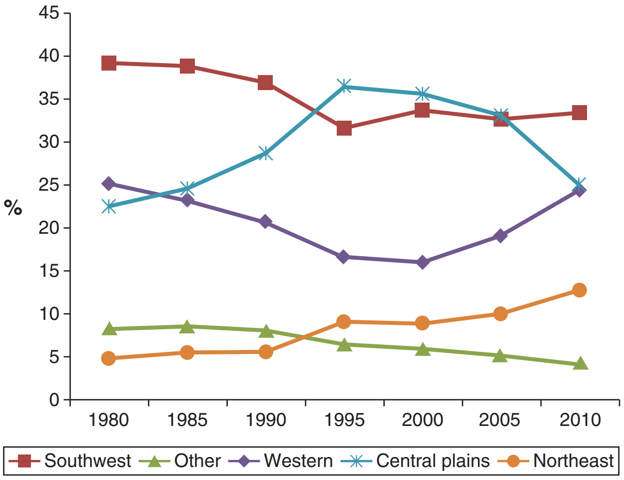


Figure 7.3: Percentage of Chinese bovine herd in five regional beef zones, 1980–2010. Source: Derived from China Livestock Yearbook (various years).

One of the most important trends is that developed parts of China play a small and diminishing role in the cattle industry, while relatively undeveloped areas play a significant and growing role. Western and south-west China, that have been less exposed to economic growth, have maintained or increased their relative importance since 2000. In contrast, 'other' provinces such as the highly industrialised Guangdong and Beijing are abandoning cattle production, although peri-urban areas in cities like Beijing have significant abattoir and vertically integrated structures promoted in the name of local food security and safety.

In the still relatively undeveloped zone of south-west China, cows are still used for draught and transport purposes in cropping systems, which are often hilly areas not suitable for machinery (or large-framed draught cattle). The small cows are fed a low-grade diet which results in some of the lowest productivity (i.e. turnoff and carcass weight) indicators and the lowest scale of production indicators in China. While the relative importance of the region dropped from 1980 to 1995, the south-west has maintained about one-third of the bovines in China over the last 15 years, although this includes a significant number of buffaloes.

From a small base, the north-east zone has grown at the fastest and most consistent rate to account for 13% of China's bovines. This reflects resource advantages in the region, especially in feed grain (mostly corn). The north-east has by far the highest average carcass weights and the highest scale of production, and a relatively high proportion of cattle are turned off through feedlots.

The north-west zone and provinces like Inner Mongolia, Xinjiang and Tibet have traditionally been associated with extensive grazing systems. However, few cattle are produced in ‘pure’ extensive pastoral systems and even these pastoral areas have undergone intensification (i.e. pen feeding) due to grazing bans design to arrest grassland degradation in the region (Brown *et al.* 2002). Most cattle are raised in semi-pastoral systems and in cow–calf systems and turned off to agricultural areas for further feeding or slaughter. The relative importance of the region has increased over the last decade (24%) due to an increase in beef cattle numbers in Ningxia and Gansu, and dairy cattle in Inner Mongolia and Xinjiang in the early 2000s.

Bovines are most densely concentrated in the Central Plains zone, especially in Henan, Shandong and Hebei. From a modest production base of draught cattle and crop residues, the region grew to hold 36% of China’s cattle through the 1990s. However, farmers in the region have relatively good access to labour and urban migration opportunities. This diminished the relative importance of the region, to 25% of China’s cattle in 2010. The farmers that remain are becoming increasingly commercialised, as suggested by the highest turnoff rates in the country.

Shandong Province in the Central Plains zone provides an illustration of the industry commercialisation process in a relatively well-developed part of the country. With once the biggest cattle herd in China, it is now eighth with a declining bovine herd but it remains the second biggest beef producer. Once a major cow–calf production area, the province is increasingly importing feeder cattle from other provinces for feeding and slaughter to service provincial and nearby (e.g. Beijing) markets. This is reflected in a turnoff rate of 93% and relatively heavy average carcass weights of 151 kg.

Scale of production data (China Livestock Yearbook, various years) reports the proportion of beef cattle turned off through farms or feedlots in specified scale categories. For China as a whole, 59% of all beef cattle are turned off by households that turn off one to nine head per year. In Shandong the corresponding percentage was 50% in 2010, a large reduction from 72% in 2005 (Fig. 7.4). Growth has occurred in larger feeding households (10–49 head) and in the feedlot sector which is small by western standards (i.e. the 1000 head throughput per year on a 90-day feed regime represents 250 head on feed at any one time).

In agricultural areas like Shandong, the scale category of one to nine head refers predominantly to cow–calf households, while larger-scale categories are engaged in fattening. While some areas (e.g. western China and the north-east) have a comparative advantage in cow–calf production, sometimes on a larger scale (10–49 head), there are concerns about the contraction of the cow–calf sector in central China, raising the question of who will produce China’s cows and calves into the future. Processors and some arms of government have lobbied for cow–calf production subsidies (as is done for sows), but the bid was rejected by higher levels of the state.

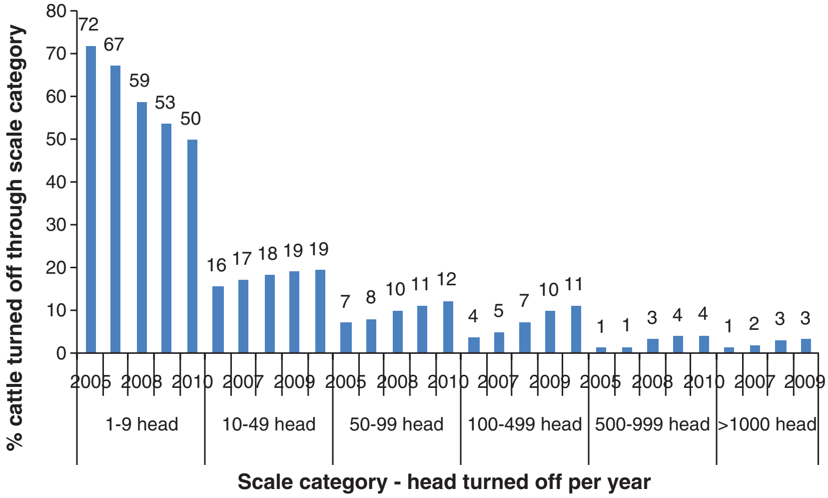


Figure 7.4: Scale of cattle production in Shandong Province, 2005–10. Source: China Livestock Yearbook (various years).

A representative cattle production system

In order to provide a picture of cattle production systems in China, this section presents a typical small-scale cow–calf household in Shandong Province. This portrait has been established through fieldwork in Shandong in 1998 and in 2006 based on detailed household surveys, the construction of biophysical and economic models of the systems and expert input from officials, extension staff and researchers. Full details appear in Longworth *et al.* (2001), Waldron *et al.* (2007) and Waldron (2010).

In agricultural regions of China such as Shandong, households raise cattle within small-scale, integrated farming systems. Households not specialised in cattle production allocate most of their limited resources to other activities such as cropping, other livestock or off-farm work. Livestock feed and labour are not generally bought-in from off-farm sources and land is limited (average of 1 ha per household). Cattle were traditionally kept mainly for draught purposes, for ~30 days of the year to plough the fields and intermittently for transport work.

For these reasons, most households hold just one or two cows and their offspring. However, over the 1990s and 2000s, draught cattle have largely been replaced by small tilling machines and three-wheel tractors. While many households still hold one or two head as a component of integrated household agricultural system (sideline cash income, utilisation of crop residues, manure, draught, custom), others have moved into cow–calf production more specifically for beef purposes and have increased their herds to around three cows. Increases in size are most likely for households if they have access to more leased and public land, or enter into profit-sharing arrangements with other households to raise cattle.

As local cattle have been bred to provide draught power on a maintenance diet, they are relatively small and fine-boned and produce 'draught quality' beef. 'Yellow' cattle breeds in Central Plains include Qinchuan, Nanyang and Jinnan, but Luxi is the most widespread breed in Shandong. Local village bulls were in the past used for breeding, but almost all breeding in Shandong is now done through artificial insemination (AI) and straws have replaced pellets. More than half the herd are improved crossbreeds with Simmental being the most widespread, followed by Limousin and Charolais (the latter becoming less popular because of dystocia). AI fees are subsidised by the state and are paid on the basis of a successful pregnancy which can often take up to three attempts. Calving rates of 60% for a local breed cow fed on a straw-based diet crossed with a Simmental bull by AI were common in the 1990s, but this rate has increased to over 80% in the 2000s. The mortality rate of cattle in agricultural regions is low and stable at around 3% because the region does not have large climatic extremes or seasonal feed gaps and households live in close proximity to their cattle and basic veterinary care.

Unspecialised households house their cows in sheds in courtyards at night, tether them in public areas of the village on fine days and graze them along roadsides and between fields in summer (Fig. 7.5). Diets are based on straw and crop residues, and vines and weeds are cut and carried back to the pens. Diets also include small quantities of corn, soybean meal and wheat husk, and rates of concentrate feeds are increased before sale.

Calves are weaned at about six months of age by tethering them separately from the cows. Weaning weights are around 135 kg for male calves and 120 kg for females. Male calves are not castrated in agricultural regions. In the 1990s bull calves were sold at 24 months of age. Several trials show that these cattle could reach a liveweight of 400 kg in this period on a cottonseed and ammoniated straw diet (Dolberg and Finlayson 1995) but daily liveweight gains in surveyed households were lower, at around 300 g per day. Heifer calves are often sold at 24 months of age but, again, there is a wide range of incentives for households to employ different management practices. In the 2000s, household commonly sold calves at 12 months of age to minimise the losses of holding cattle in inefficient fattening systems. In the 2000s more

Figure 7.5: Specialised cattle household in Shandong. These Luxi-Limousin cross cattle are tethered in an area away from the household during the day, where much of the husbandry is done by elderly household members as younger members work off-farm. Photo: Colin Brown.

specialised and efficient fattening households and feedlots emerged to finish cattle.

The farm budgeting results for 1998 indicated that unspecialised cow–calf production *decreased* net returns because revenues (from calf sales, culled cows, draught and manure) were lower than costs (especially feed). This was particularly the case as calves were kept to slaughter age in inefficient feeding systems. However, if unspecialised households undervalue, or do not value at all, items produced and consumed on-farm, then they may perceive cow–calf production as a worthwhile activity. With changes to the production system (e.g. three cows, higher calving and growth rates and sale of calves at 12 months old) that was more common in the 2000s, the efficiency of the system improved substantially. However, households in much of Shandong have increased access to off-farm opportunities. If opportunity costs of labour are included in budgets, then net returns are even lower than in 1998.

Beef consumption

While the Chinese beef industry faces structural supply-side constraints, beef consumption increased significantly in the 2000s although these data have to be interpreted with caution. While production data in China is overstated, consumption data is understated. The National Bureau of Statistics collects consumption data for both urban and rural areas, which are derived and extrapolated from household surveys (National Bureau of Statistics, various years). The consumption figures report on in-home household consumption but not on out-of-home consumption in the hotel, restaurant and institution (HRI) trade. With increasing expendable incomes and shifting Chinese consumption preferences, this represents a major gap in the data.

To assess the degree of inaccuracy in the data, consumption can be calculated based on the 'trade-balance method' as domestic beef production, plus net trade divided by the national population. This is the equivalent of 'per capita supply' in FAOStat figures. This method has shortcomings because it is based on (overstated) production figures and does not disaggregate consumer populations. However, it provides an indication of the degree of understatement of the official consumption data, which can be assumed to be out-of-home beef consumption. If accurate, it suggests that HRI beef consumption in China is high (in relative terms), which conforms to expectations in China, especially for urban residents. Beef is served in increasingly diversified Chinese menus (e.g. 'sizzling iron beef'), in popular minority and regional dishes (hot pot, Xinjiang skewers, Hui Muslim noodles, Korean dishes) and in foreign restaurants in China (Japanese/Korean barbeque, Brazilian beef, US fattened beef), where beef is the major item on menus.

Consumption survey data reveals that the level of in-home consumption of beef remains very low in China, at just 0.63 kg for rural residents and 2.53 kg for urban residents in 2010 (Figs 7.6, 7.7). Beef consumption has stagnated in rural areas. However, the steady increase in urban areas is especially significant because it has occurred in conjunction with rapid urbanisation. While 26% (300 million) of China's population lived in urban

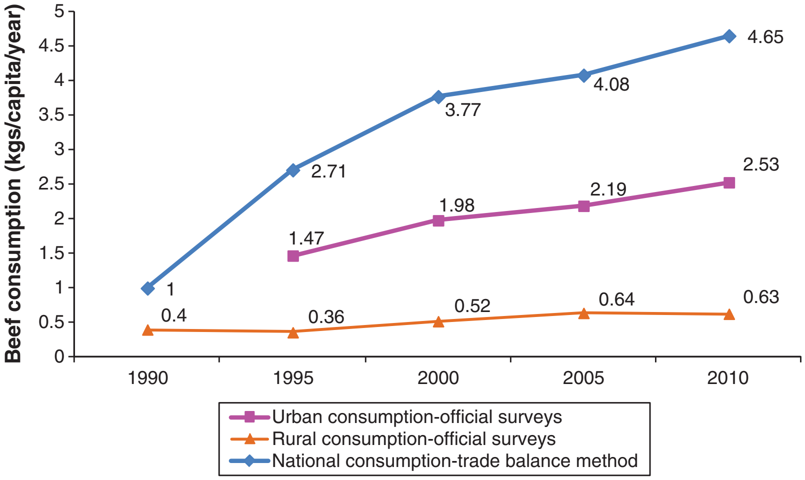


Figure 7.6: Per capita beef consumption in China, based on different sources of official data. Source: China Statistical Yearbook, China Livestock Yearbook, China Customs Yearbook (various years).

Figure 7.7: Meat market in Ji'nan City, Shandong. Sales volumes and prices of beef in wet markets have increased in cities in recent years, not just in small stalls but in franchised butcher shops that advertise different cuts, processing services, religious and food safety schemes. Photo: Colin Brown.

areas in 1990, this number increased to 50% (666 million) by 2010 (National Bureau of Statistics, various years). Per capita increases in urban in-home consumption and demographic change account for 50% each of the increase in total beef consumption in China (of 59% between 2000 and 2010). This is considerably higher than growth in beef production (23% over the period).

Beef prices

Underlying demand–supply forces have exerted strong upward pressure on beef prices in recent years, including in Beijing (Fig. 7.8). The data is collected by the Ministry of Agriculture in 'observation points' (markets) throughout China based on daily sales but averaged over monthly periods to province level to represent the monthly average prices for generic types of livestock products, including bovine meat.

Beef (and mutton) prices remained low and stable through the 1990s and the first half of the 2000s, but began to increase rapidly in 2006–08. This followed food price increases in China and internationally. Beef (and mutton) prices in China maintained high price levels thereafter. Pork prices declined over the period partly because of state storage and production subsidies. Beef prices continued to rise throughout 2011 and 2012 according to another price series (China Animal Agriculture Association). At Rmb39 kg, this equates to approximately US$6 per kg of generic, undifferentiated 'beef'.

The trade sector

Increasing beef prices raise the prospect of increased trade. Trade flows are discussed here through data reported in UNComtrade data for all types of bovine meat (fresh/chilled and frozen, carcass forms and cuts, bone-in and bone-out). Compared to the domestic sector, China has historically had a very small beef trade sector both for imports and exports. However, the absolute volumes have increased, making China a more significant player in the international beef market.

Mainland China has been a net exporter of beef for nearly all of the past 20 years. Exports are mainly

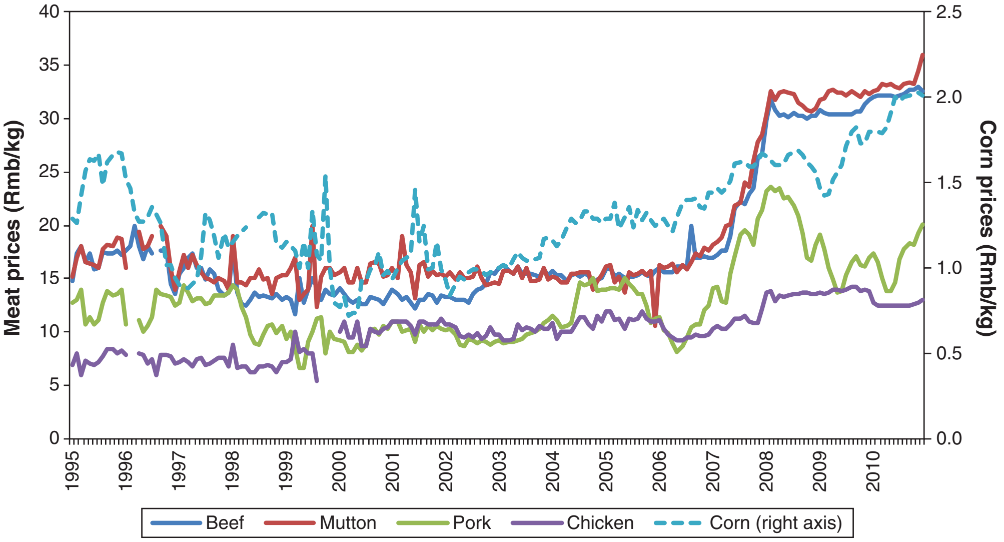


Figure 7.8: Monthly bovine meat prices in Beijing, 1995–2010. Source: China Livestock Yearbook (various years).

low-value (average of US$5 kg in 2010–11) to South-East Asia and the Middle East. China has historically imported only modest amounts of beef. The vast bulk of beef imports are frozen for processing at an average value lower than the export trade. However, the low volume of fresh or chilled beef (0.5 kt, virtually all from Australia) sells for nearly five times the price (US$18 kg in 2011).

Although still accounting for a tiny proportion of domestic production, the volume of direct beef imports into China increased to around 20 kt in the period 2009–11 (Fig. 7.9). Most of the beef is frozen and all is from countries with protocols (foot and mouth disease (FMD) free) to export to China (i.e. Australia, New Zealand and Uruguay). At the same time, volumes of beef imports into Hong Kong increased rapidly, almost all of it frozen and from countries without protocols to export to China (i.e. Brazil, the USA and Canada). Part of this increase in beef imports can be explained by decreases in modest live cattle imports into Hong Kong and official re-exports of beef to other Asian countries, especially Vietnam. Domestic consumption in Hong Kong is unlikely to have changed much (around 60 kt per year). The major reason for the increased imports into Hong Kong is that it is unofficially re-exported into China. Up to 40 kt of beef may have been smuggled from Hong Kong into mainland China in 2011, and more through Vietnam.

Beef offal is officially and unofficially imported into China on a much larger scale. Waldron *et al.* (2007) calculated that 43.5 kt was smuggled from Hong Kong into mainland China in 2005. This amount is likely to have increased manyfold since (Fig. 7.10). Brazil and Argentina are by far the biggest suppliers.

The high incidence of smuggling reflects price relativities and trade policy settings. China has not established import protocols with many South and North American countries for major infectious diseases (FMD and BSE) and applies total country (not area-based) bans. In addition to 13% VAT, China applies import duties that range from 25% for frozen carcasses to 12% for most beef and offal products for countries with most favoured nation (MFN) status. While the costs of smuggling – transport from Hong Kong to other (including northern) parts of China and pay-offs to border authorities – are said to be increasing, they are still lower than import duties and taxes.

While not reflected in Figs 7.9 and 7.10, trade patterns changed in 2012 as China moved to enforce official import regulations and rein in grey channels leading up to elections of the new session of the National People's Congress in March 2013. This led to a much publicised three-fold increase in official, direct beef imports into China of 61 kt. While a significant trade, it represents just 1% of China's domestic bovine meat production, a figure that highlights the importance of domestic production in forging trade patterns.

INDONESIA

The Indonesian cattle industry has a fascinating history of breed development that fits into an intricate tapestry of farming systems and livelihood strategies, overseen by a large hierarchy of administrative, service and research institutions. Cattle form part of rich cultural systems including ceremonial uses, while beef is a key ingredient in some of Indonesia's most famous dishes

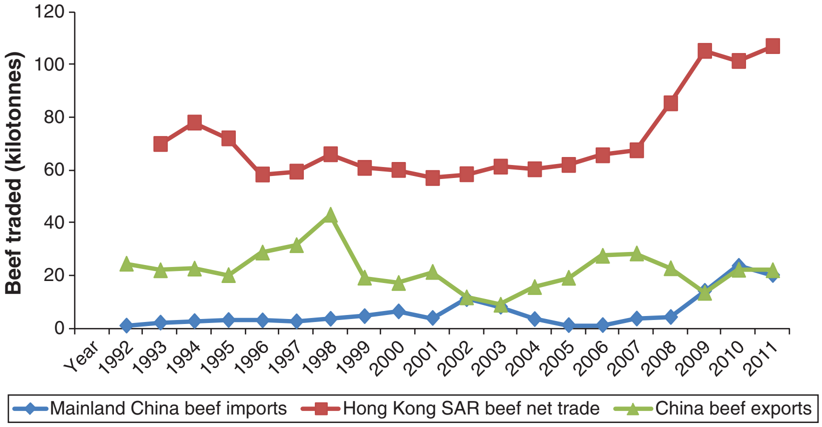


Figure 7.9: Beef imports and exports, mainland China and Hong Kong Special Administrative Region (SAR), 1992–2011. Source: UNComtrade (2012).

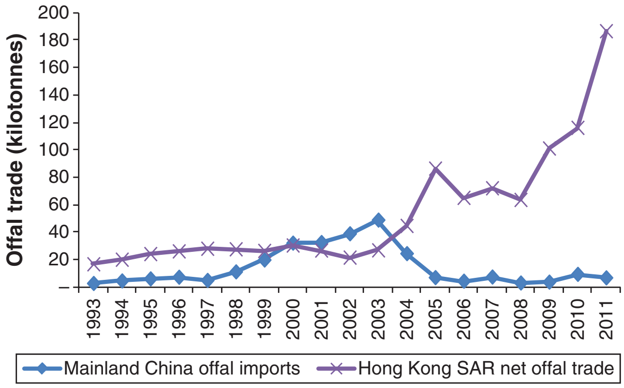


Figure 7.10: Beef offal imports into mainland China and Hong Kong, 1992–2011. Source: UNComtrade (accessed June 2011).

such as bakso and rendang. Statistical analyses provide some insights into developments in the Indonesian beef industry. Given the importance of statistics in policy formation and trade relations and the paucity of detailed statistical analysis on the Indonesian beef industry reported in English, this section seeks to fill an important void.

Statistics

Production indicators for the Indonesian cattle and beef industry (Fig. 7.11) is drawn from the Director General of Livestock and Animal Health Services (DGLAHS), which collects cattle production data on an annual basis from reports submitted by local government offices responsible for livestock services. Statistics reported by DGLAHS are equivalent to those reported in FAOStat for cattle production and cattle meat production. However, statistics of the DGLAHS on cattle slaughter are higher and are regarded as more accurate than those of FAOStat or the Indonesian Central Statistics Agency (BPS). DGLAHS slaughter statistics are used in this section, which have a bearing on derived indicators (e.g. slaughter rates and average carcass weights).

From a cattle herd of just 6 million in 1979, numbers increased significantly in the early 1980s. Hadi *et al.* (2002) attributed this to large international projects

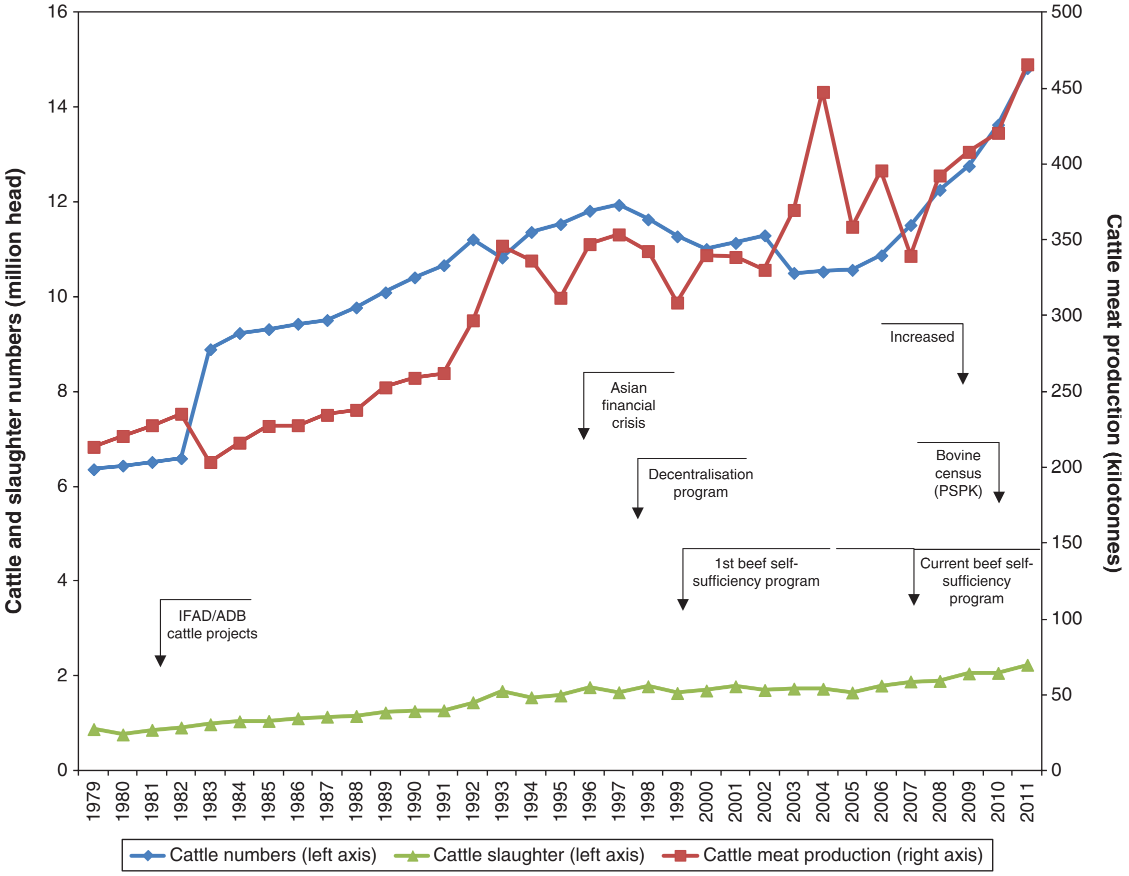


Figure 7.11: Production trends and policies in the Indonesian beef industry, 1979–2010. Source: DGLAHS (various years).

(IFAD and ADB) which introduced new breeds (i.e. Charolais and Brahmans) that increased productivity. Cattle numbers rose steadily over the 1980s and into the early 1990s, and were boosted by imports in the mid 1990s that peaked at 424 000 head in 1997. The 1997 Asian financial crisis and the heavy depreciation of the rupiah saw imports crash, while farmers capitalised on the resultant high prices by selling cattle, including breeders.

With economic recovery in the 2000s, Indonesia's cattle herd and productivity grew. So too did cattle imports (Chapter 12) from 2004 to reach a peak of 781 000 head in 2009 to constitute 6% of the cattle herd and 38% of slaughter numbers. From this peak, imports had halved by 2011 due to import restrictions.

In developing industry policy, Indonesian policymakers were working off data from the last agricultural census of 2003. In 2011 the Ministry of Agriculture and the Central Statistics Agency conducted the national bovine census, called the Data Collection of Beef Cattle, Dairy Cattle and Water Buffalo (PSPK). This found that the national herd had already reached 14.8 million head, well above the figure used in annual reporting (12.6 million head). Based on these numbers, projections for 2013 and 2014 were increased to 16 million and 16.8 million head. The bovine census provided much-needed updated and disaggregated data on the profile of the Indonesian cattle herd, including regional distribution, age, sex and breed. There is a further opportunity to assess the statistics, in the 2013 agricultural census.

Statistical indicators suggest that cattle numbers increased by an average of 5.3% per year in the 1980s, 0.4% in the 1990s and 2.3% in the 2000s. These rates are widely thought to be below potential as cattle productivity is low and can be increased by smallholders adopting simple production and management practices. There is also thought to be potential to more fully utilise plantation residues (e.g. in Sumatra), crops residues (e.g. in Java) and pastures in provinces like Nusa Tenggara Barat (NTB) and Nusa Tenggara Timur (NTT). There is also widespread concern about the slaughter of productive females, especially in periods of rising cattle prices. It is stated in Beef Cattle and Buffalo Self-sufficiency program (PSDSK) policy documents that 150 000–200 000 productive cows are slaughtered per year (7–9% of total slaughter) mainly from cow–calf breeding areas of NTT, NTB, Bali and Java. This, however, is not reflected in provincial statistics. According to NTB Dinas Livestock statistics, females accounted for 64% of all cattle and 79% of adult cattle in NTB in 2010, with virtually no change since 2001.

Even though statistics derived from the DGLAHS are higher than those of FAO or BPS, they still underestimate slaughter numbers because they do not account for illegal slaughtering. DGLAHS slaughter figures derive from reports from staff of slaughterhouses and from Dinas officials who check slaughter based on interaction with village leaders, consumption patterns and fee and tax collection. However, they are not able to report on all local-level slaughter activity and uncertified slaughterers. In the case of Mataram City in NTB, illegal slaughtering was estimated as 25% (Hermansyah and Mastur 2008). In NTT province, statistics are kept on cattle slaughtered in and out of slaughterhouses. For the provinces as a whole, 17% are slaughtered out of slaughterhouses, but this can be as high as 41% in places like Sumba (BPS 2011).

While not discernible in Fig. 7.11, slaughter numbers fluctuate significantly year to year. They increased at an average rate of 4.3% per year in the 1980s, 3.3% in the 1990s and 1.7% in the 2000s. Comparing growth rates for cattle with slaughter numbers provides slaughter rates. From 13.3% in 1980, slaughter rates decreased in the 1980s, increased in the 1990s and decreased in the 2000s to reach 15.2%. However, if illegal slaughtering is taken into account, then slaughter rates may be as a high as 19% in 2010.

Long-term cattle meat production has increased broadly in line with slaughter numbers (1.4% in the 1980s, 2.9% in the 1990s and 2.4% in the 2000s). Thus, average carcass weights have changed little, to remain at 203 kg in 2011. However, if illegal slaughtering is taken into account then the average carcass weight (which includes imported cattle) decreases to 159 kg, more in line with expectations of observers of the Indonesian cattle industry. Average carcass weights for NTB province are recorded as 140 kg in official statistics.

Policy

Indonesia has an extensive administrative and service systems engaged in industry activities including breeding, feeding, animal health, transport, marketing and slaughter. However, the most widely publicised flagship policy is the beef self-sufficiency program.

From the 1960s, Indonesia has had long-term self-sufficiency programs for commodities like rice. Objectives of self-sufficiency, price stability and food security heightened with the onset of the Asian financial crisis in the late 1990s. Beef was introduced into Indonesia's self-sufficiency programs in 1999 on the basis that Indonesia has high import dependency for cattle and beef, that beef is a part of a diversified diet and that the industry comprises a large number of low-income producers (4.2 million livestock producers, although fewer specifically raise cattle). The first program aimed to achieve self-sufficiency in beef by 2005 (Ilham 2006) and another cabinet launched a second program to achieve self-sufficiency by 2010.

Interest in self-sufficiency reignited in the late 2000s with international food price spikes and international preoccupation with food security. Indonesia's National Medium-Term Development Plan (2010–14) targeted five commodities to achieve 90% self-sufficiency by 2014 – rice, soybean, sugar, corn and beef. The Beef Cattle and Buffalo Self-sufficiency program (PSDSK) began in 2008 with the aim of increasing the cattle herd by 2014 to 14.23 million head and beef production to 420 200 tons, which was to restrict imports to 32 000 tons. Self-sufficiency is thought to be 'easier' to achieve for beef than other commodities because pen-feeding cattle production is not land-intensive. Results from the bovine census (see above) were used to pronounce that the 2012 target had been achieved, the PSDSK program was on track and that the budget planned for the program could be pared back (Prabowo 2011).

Previous self-sufficiency programs were underresourced and had variable impacts on production, but funding has increased dramatically in the current PSDSK (Prabowo 2011). The government allocated Rp10.65 trillion over five years, of which Rp1.5 trillion was allocated for 2013 (which equates to US$156 million per year, or US$10 per head of the Indonesian cattle herd).

Self-sufficiency programs over the 2000s have common elements. The heavily production-oriented policy includes:

- breeding measures, including AI and village breeding centres;
- slaughter bans and the 'rescue' (buy-back) of productive females for redistribution;
- cattle distribution schemes, where the government give cows to members of farmers groups, who then return calves (one to three) back to government for redistribution;
- credit schemes, where banks make loans to cattle producers with interest rates subsidised by government, for either small-scale fattening or larger-scale cow-calf production;
- relationships between 'nucleus' companies (importers, plantations, feedlots, abattoirs, traders) and 'plasma' producers (smallholders, production groups);
- trade policy.

Since the colonial era the Indonesian government has restricted the domestic trade of cattle and designated particular breeds to particular regions, an approach that continues. Diseases are contained by restrictions on the movement of cattle, especially breeding cattle, from affected regions or islands. Local governments also pursue local industry development plans through export quotas (for cattle in different sex, age, weight or height categories) and the import and redistribution of breeders.

Similar policy instruments are used to regulate international trade. Following broader liberalisation measures and accession to trade groups (including the WTO in 1995), Indonesia adopted a liberal trade policy to cattle and beef. This is particularly the case for tariffs. No tariff is applied to breeders, on the rationale that they grow Indonesia's herd (although these make up a very small proportion of cattle imports). Feeder cattle were also imported duty-free, subject to the requirement of the maximum weight of 350 kg on the basis that the value of weight gain is captured by Indonesian feedlots and used in breeding schemes. A 5% tariff is imposed on imported beef and offal. Under the ASEAN, Australia and New Zealand Free Trade Agreement tariffs on bovines, beef and beef offal are to be eliminated or phased out.

Trade policy has, however, become increasingly protectionist in recent years, particularly towards Australian imports. This coincides with the most recent self-sufficiency program and is accentuated when animal welfare concerns led the Australian government to ban the export of live cattle to Indonesia for a month in 2011 leading into the peak consumption period of Ramadan (Chapter 12). Trade restrictions include stricter enforcement of the 350 kg limit, while in 2012 a 5% tariff was introduced for cattle imports except 'oxen and breeders' (Nason 2012a).

The allocation of quota is by far the major policy instrument used to restrict imports. This is effectively done through reduced allocations of import permits. From a peak of 781 000 head of live cattle imported in 2009, Indonesia imposed a quota of 520 000 head to be imported from Australia during 2011 and 283 000 during 2012. For beef, from a peak of 91 000 t in 2010, imports of boxed beef have also declined due to quota restrictions. After additional quota were issued in 2012 (8300 t and 7000 t), the total allocation was 41 000 t, or ~10% of Indonesia's beef production.

Indonesia imposes total country bans (not based on area of freedom) for FMD. Australia, New Zealand and Uruguay are FMD free while Brazil and India are not 'allowable country of imports' for beef. Measures to relax the laws were rejected by parliament in 2010 although press reports suggest that the issue will be revisited (Nason 2012b).

Industry policies such as cattle distribution, slaughter bans, credit schemes and domestic trade restrictions pose major administrative and financial demands on government. Various international studies have modelled the efficacy of different policy measures. Hadi *et al.* (2002) and Vanzetti *et al.* (2010) both find negative net welfare effects from international trade restrictions, and that the most effective policy area to benefit smallholder producers and consumers is research and development to increase the productivity of native cattle (although this can have lagged time to impact). Vanzetti *et al.* found that cattle distribution and credit provision has a neutral impact. Rather than a production-side approach to industry development, Deblitz *et al.* (2011) argued for a whole-of-industry and market-led approach.

Regional distribution and issues

Figure 7.12 provides a snapshot of the distribution of beef cattle by province in 2011. Table 7.2 presents data on beef cattle indicators aggregated to a regional level, also drawing on statistics from the 2011 bovine census.

Three main cattle breeds are identified in the statistics – Bali, Ongole (imported from India by the Dutch) and Madura (originating from the island in East Java by the same name). The remainder ('Other') are Limousin, Simmental and Brahmans or their crosses. Bali, Ongole and 'other' breeds each make up roughly 30% each of Indonesia's cattle, with Madura accounting for the remainder. Female breeders make up around 68% of all cattle in Indonesia, with little difference by region (or province). Differences in age profiles of cattle are also subtle, but some exceptions are noted below.

The highest and most dense cattle population is in Java, which holds half the national beef cattle herd. Some 57% of Indonesia's human population also live in Java. Cattle numbers in Java have grown at rates below the national average, perhaps reflecting resource (especially land and labour) constraints, which is significant given the number of cattle. Ongole crosses are the most populous breed, but East Java in particular is also the major centre for the Madura breed. 'Other' breeds that have been introduced for fattening and for distribution schemes make up 30% of the cattle herd.

For Java as a whole, 42% of the male cattle are yearlings (the highest in the country), while this figure is above 50% for provinces like West Java and Banten. Accordingly, these provinces have very low proportions of female breeders. Java also has the youngest herd, with only 27% being 'adult' (i.e. older than yearlings). In upland areas, farmers tend to keep cattle longer and sell mature animals. In all areas, cattle are kept primarily for cash income and only secondarily for draught power and manure. Java also has several large feedlots and mechanised abattoirs.

While Sumatra has a much smaller cattle herd, it is the next largest in Indonesia and has grown at the fastest rate. While most cattle are produced in smallholder systems, there are large feedlots throughout Sumatra that utilise feeds from plantation estates (palm, pineapple, cassava etc.). Reflecting the greater focus on fattening (and imported cattle), Sumatra has the highest proportion of imported crossbreeds in Indonesia. While the island has

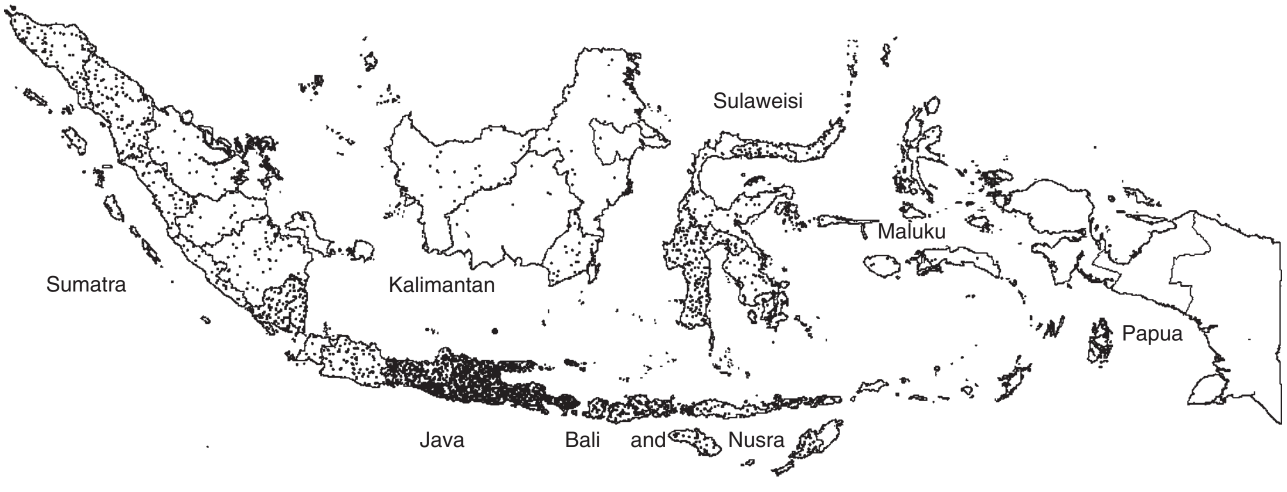


Figure 7.12: Distribution of beef cattle population in Indonesia by province in 2011. One dot equals 5000 cattle. Source: Map generated by authors. Data from MoA and BPS (2011).

Table 7.2: Cattle indicators for regions of Indonesia, 2011

	Indonesia	Java	Sumatra	Bali and Nusra	Kalimantan	Sulawesi	Maluku and Papua
Total cattle (million head)	14.8	7.5	2.7	2.1	0.4	1.8	0.3
% of national herd	100	51	18	14	3	12	2
Average annual growth, 2003–11	5.3	3.9	9.7	5	4.9	7.8	4.8
Breed composition (% of herd)							
Bali	32	3	25	95	63	79	83
Ongole	29	42	29	4	11	8	14
Madura	9	16	2	1	12	0	2
Other	30	40	44	0	14	12	1
Sex							
% females in herd	68	68	68	67	64	71	67

Source: MoA and BPS (2011).

traditionally focused on supplying the Jakarta market, recent economic growth in the island has seen increasing intra-island demand.

The Bali and Nusra (NTB and NTT) region in eastern Indonesia has a drier tropical climate, a longer distinct dry season, a higher incidence of seasonal grazing, poor soils and significant feed gaps. Most cattle are the Bali breed, which is adapted to the harsh conditions and low input-output systems and maintains high fertility and conception rates. However, catlle are small in size and have low growth rates, while low feed inputs and milk production and harsh climatic conditions can lead to high calf mortality and long calving intervals (Mastika 2003). While there are very few other cattle breeds in the region there are large numbers of water buffalo in Bali and Nusra (12% the number of beef cattle) but numbers are declining. Bali–Nusra is regarded by industry as a cow–calf production region but this is not reflected in herd composition statistics (age, sex) compared with other regions and over time. The region has been a traditional exporter of live cattle, although numbers have been constrained by quota allocation in recent years (Fig. 7.13). As an indication of the volumes, in the peak year of 2009, NTB province exported to other provinces (especially Java) 15 000 slaughter cattle, 13 500 breeding cattle and 9500 buffaloes.

Figure 7.13: Bali cattle at market in Lombok. Like most of China and South-East Asia, most cattle are traded through spot transactions in periodic markets populated by a large numbers of farmers, transport operators, brokers, traders and butchers. Photo: Scott Waldron.

The incentives of farmers are driven by developments in the broader economy and by resource endowments. Deblitz *et al.* (2011) showed that when opportunity costs of labour, land and capital are taken into account, producers in NTT and NTB are more profitable (and therefore competitive) than producers in Sulawesi. Rutherford *et al.* (2004) produced similar findings in the cases of Sumbawa (less developed, more extensive systems) and Lombok (more developed, more intensive systems).

A representative cattle production system

Most cattle in Indonesia are held by smallholders in integrated crop–livestock systems. In some areas there is specialisation (cow–calf or fattening) but mixed systems predominate, where breeders produce calves that are grown out to slaughter weight. Most cattle are kept for sales rather than draught value. Crop residues are a source of feed in all areas but the relative importance in the diet varies by agro-climatic conditions.

At the most extensive end of the continuum are areas in eastern Indonesia like Sumba, where rainfall is low and concentrated in a short wet season. Farmers plant one crop of corn per year; the silage and stubble is used for cattle feed but only as an occasional supplement to grazing on open savannah grasslands.

In semi-intensive systems in areas like West Timor and Sumbawa, farmers can plant one to two crops per year. Cattle spend much of the year grazing on grasses and shrubs on unused land and roadsides and on stubble. However, they are confined to pens at night or during parts of the year when grazing provides inadequate nutrition or damages crops.

At the most intensive end of the continuum, lowland areas of East Java (similar to Bali and Central Lombok) have a long wet season and fertile, irrigated land. Farmers plant two to three crops per year of corn and rice, but high population densities result in very small cropping areas (0.4 ha). The crop residues are cut and carried to cattle tethered in pens, with only small windows of time for grazing stubble. These on-farm feed resources support just a few head of cattle per household. To limit feed demands, farmers in lowland areas like Probolinggo are increasingly specialised in cow–calf production. In recent years there has been a rapid increase in the trade of even low-value rice straw by large numbers of feed traders (Priyanti *et al*. 2012).

In the less intensive rainfed and seasonally dry upland areas of East Java like Malang, farmers only plant two crops per year, have lower yields than lowland areas and larger land areas. Farmers also hold cows that produce calves, but most are fed to slaughter weight in mixed systems. Srigonco village in Malang is an example of an upland area in East Java that is monitored in the ACIAR Project LPS2008/038 (Straw Cow project). The village contains 1250 households, 1559 cattle, 563 cattle owners and another 100 that 'keep' cattle for 'owners' in a profit-sharing arrangement. Household herds vary between two and four head (Fig. 7.14). The cattle are predominantly Ongole crosses, but there is increasing demand from farmers for Euro crossbreeds. Almost all breeding is done through artificial insemination. Households phone local AI technicians when the cow shows signs of oestrus, but the timely delivery of AI services is an important determinant of calving rates, which can be as low as 40%.

Figure 7.14: Bali bull in a pen in Lombok. Photo: Scott Waldron.

A 'typical' household in Srigonco village has the following characteristics:

- the household raises two Ongole cows which are artificially inseminated to produce calves that are fed and sold at 30 months of age. Cattle are not used for draught purposes. Manure from the cattle is used on own fields;
- the household has 0.75 ha of cropping land (including 0.2 ha rice, 0.2 ha corn, 0.25 ha corn crop relayed with rice) and some inter-cropping (e.g. cassava). Tree legumes (sesbania) are planted on bunds, king grass planted on dykes and native grasses and shrubs in the village are seasonally accessible;
- cattle are fed on rice straw, corn stover and forages (sesbania and king grass) and grazed occasionally. They are tethered in a small open-sided bamboo/thatch pen;
- farm labour consists of a mother (who does most of the animal husbandry), a child (who occasionally herds animals) and a father, who works about half his time off-farm (construction, transport). Everyone in the household collects feed;
- the household collects some straw from its own rice and corn crops, but the majority is from off-farm sources. The farmers assist other households in the village to harvest rice every second day in exchange for straw. They also hire a truck together with other neighbours once per month to collect straw from farms ~20 km away. In both cases, the feed itself has no value, but there are significant labour and transport costs associated with collection.

The cattle production systems are best described as low input–low output. Long-standing research has measured the productivity effects of introducing a suite of simple, low-cost and integrated measures. These include supplementary feeding of cows, better detection of oestrus, early weaning and calf management, improved feed management and improved pens/sanitation and water.

Waldron *et al*. (2013) budgeted the economic impacts of moving from a low productivity to an improved productivity system based on the following parameters: mortality decreases from 5% to 0%; calving rates increase from 40% to 60%; weaning age decreases from seven to six months; weaning weight increases from 90 kg to 109 kg; and liveweight gain increases from 0.3 kg to 0.4 kg/day. These measures increase the turnoff of cattle (20%) and the weights of cattle sold (by 35%).

In the low productivity systems gross profits from cattle production are positive, but net profits become marginal if the capital costs of the cattle inventory are valued, and negative if family labour is valued. In the improved productivity systems gross and net profits are both positive, even if family labour is valued. The budgeting also finds that there are far higher returns to cattle owner-keepers than to keepers in both low or higher productivity systems, suggesting that measures to increase cattle ownership is an important way of increasing rural incomes and the uptake of improved production practices.

Beef consumption

Consumption data is drawn from the Household Food Expenditure and Consumption Surveys reported in national socio-economic household survey (SUSENAS) conducted by the Bureau of Statistics (BPS). BPS conducts surveys of large numbers of households nationwide (75 000 in 2011) and reports on household expenditures and quantities both in and out of home on a weekly basis.

Household total protein intake increased with national economic recovery from 1999 to 2002 (Fig. 7.15). Intake from fish and eggs/milk increased over the 2000s while intake from cereals decreased. Protein intake from beef also grew from 1999 to 2002, but stagnated thereafter.

Figure 7.16 breaks down the composition of the meat group through a snapshot of meat consumption in 2010. The data disaggregates four major meat types: ‘preserved meat’, ‘offal and bone’, ‘meals’ and ‘fresh meat’. The data further disaggregates within these meat types.

The greatest proportion of meat purchased by households is ‘fresh’ (which actually means meat that is fresh, chilled or frozen, but not transformed) and cooked at home. Poultry is by far the most consumed meat, followed by beef as a distant second. Fresh beef accounts for just

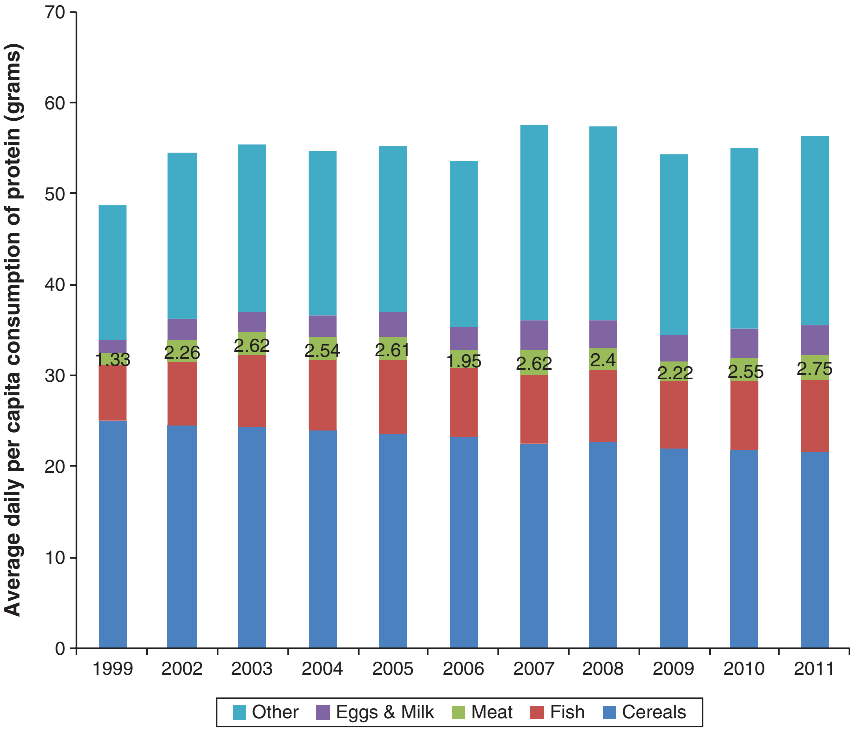


Figure 7.15: Household protein intake by selected food groups in Indonesia, 1999 and 2002–11. Source: SUSENAS, BPS reported in DGLAHS (various years).

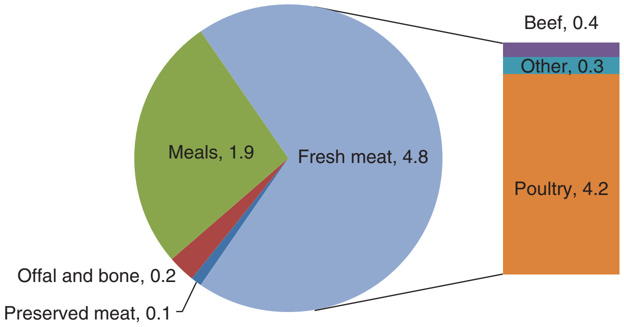


Figure 7.16: Annual per capita consumption of meat products in Indonesia, 2010 (kg). Source: SUSENAS, BPS reported in DGLAHS (various years).

0.37 kg per capita per year; levels declined from 0.57 kg in 2002 and 0.42 kg in 2007.

Reported figures of fresh meat consumption do not represent absolute beef consumption in Indonesia for several reasons. First, SUSENAS surveys may underestimate consumption for methodological reasons (respondent recall and knowledge) (Subakti 1995). Second, a large proportion of beef is consumed in the form of meals and falls into the meat 'meals' category (e.g. soups, soto, gule, rawon, sate, tonseng, goreng, bakso). If beef accounts for (say) half the meat used in meat 'meals' (Fig. 7.16), then meat consumption increases to 1.3 kg per capita per year. This figure resembles the 'per capita availability' of beef of 1.4 kg in 2010 that is calculated by DGLAHS annually (based on FAO Food Balance methods). Note, however, that food balances that are reported by the FAO are higher.

With this background in mind, questions arise about the determinants of beef demand into the future. Consumption studies provide some insights (Hutasuhut *et al.* 2001) that draw on SUSENAS data. Drivers of beef demand include:

- population growth of 1% per year, though based on the above figures this would increase beef consumption by just 3500 t per year;
- an urbanisation rate of 1.7% per year, which is significant given findings (Hutasuhut *et al.* 2001) that expenditure elasticities for beef are higher in urban areas than in rural areas;
- growth in per capita incomes, which is significant given findings (Hutasuhut *et al.* 2001) that expenditure elasticities for beef are positive (but lower than for chicken);
- the high price of beef in Indonesia constrains consumption. Hutasuhut *et al.* (2001) found that own-price elasticities for beef are negative (but inelastic compared to chicken, suggesting that beef has fewer close substitutes);
- positive cross-price elasticities suggest that chicken is a substitute for beef (i.e. if the price of the chicken increases the quantity of beef demanded will increase).

Beef prices

Beef prices are a critical indicator of dynamics in the Indonesian industry. Figure 7.17 presents beef prices in three cities (Jakarta, Surabaya and Denpasar) and, for

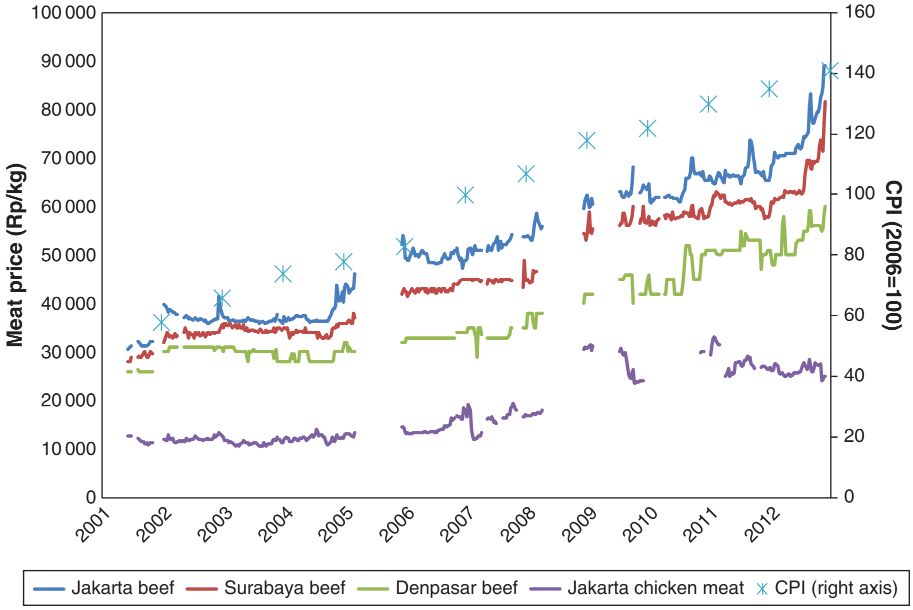


Figure 7.17: Inflation and beef and chicken meat prices in selected Indonesian cities, 2001–12. Source: MoA (various years).

comparative purposes, chicken meat prices in Jakarta and an inflation index. The data are drawn from weekly price observations collected by the Ministry of Agriculture across a range of cities in Indonesia. Beef prices represent the wet market prices for prime cuts (fillets).

Beef prices in Indonesia are high by world and regional standards. Over the 2001–12 period, beef was an average of three times more expensive than the most highly consumed meat, chicken (China has drawn close to this relativity). High beef prices in Indonesia reflect high costs at various stages. As a reflection of the transport and arbitrage costs, the price of beef in Jakarta is considerably higher than it is in cattle production areas to the east; an average of 11% higher over the period than in East Java (Surabaya) and 35% higher than in Bali (Denpasar). Prices tended to move together in the short term, suggesting an integrated beef market.

Beef prices increased at an average of 7.7% per year between 2001 and 2011 in Jakarta (only slightly higher than in the eastern cities). However, these prices were in line with increases in chicken prices, lower than average inflation rates and lower than GDP and income increases, making beef no more expensive for the average consumer. That is, beef prices did not increase in real terms over that period. Beef prices increased in the month around Ramadan (Muslim fasting period) and the festive period (Idul Fitri) by 10% in 2010 and 8% in 2011. In 2012, beef prices in Jakarta increased as expected for these festivals but then did not decline over the latter half of the year (Fig. 7.18). Import restrictions on beef and cattle are the most obvious explanations.

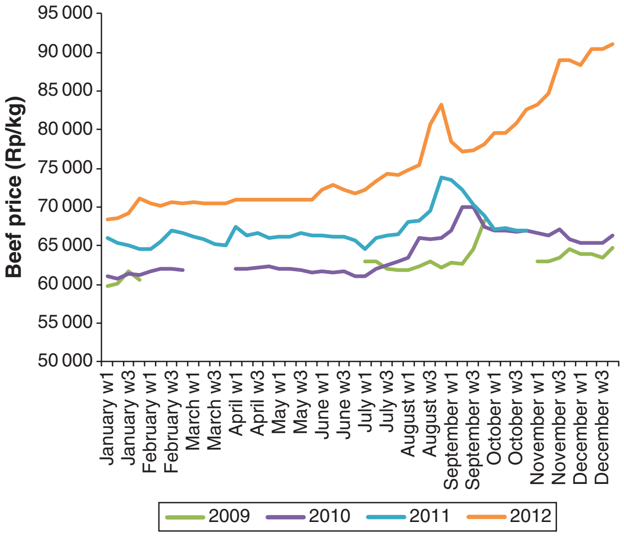


Figure 7.18: Yearly and seasonal variation beef prices in Jakarta, 2001–12. Source: MoA (various years).

The international trade sector

The combination of policy, production, consumption and price factors culminate to forge a dynamic trade sector for cattle, beef and offal (Fig. 7.19). Indonesia has a large import sector relative to domestic production, and imports increased rapidly over the 2000s for both cattle and beef.

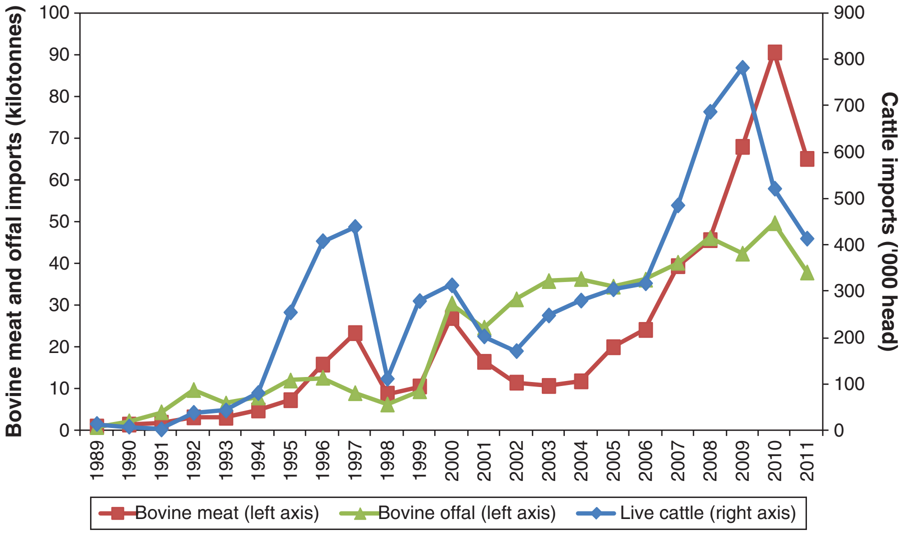


Figure 7.19: Indonesian imports of bovine meat, offal and cattle from world/all sources, 1989–2011. Source: UnComtrade, FAOStat and MLA. Note: UNComtrade and DGLAHS statistics are accurate for beef and offal imports, but underreport cattle imports. FAOStat report accurate cattle import statistics but are not up-to-date, so figures drawn from DAFF (through MLA) are used for 2010 and 2011.

Virtually all live cattle imported into Indonesia are from Australia, and virtually all of these are feeder cattle rather than breeders (Chapter 12). The average unit value of imported feeders in 2009 was US$560 (if 350 kg, this equals US$1.60 per kg). Virtually all beef imports are from Australia and New Zealand in frozen form. The average value of imported frozen beef in 2011 was US$3.5 kg, and US$5 for fresh beef. A significant amount of buffalo meat is smuggled in from India.

Imports of offal increased at a slower rate than beef and cattle imports in the 2000s. However, there was a large increase in value from US$0.60 kg in 2003 to US$2.30 kg in 2011. Most of offal has come from Australia and New Zealand, but the USA became a significant supplier in 2010–11.

CONCLUSION

There are close parallels between the cattle production systems of China and Indonesia. Most cattle are kept by unspecialised households as part of smallholder farming systems. Intensive and vibrant production and trading systems in certain parts of Indonesia (e.g. Java) closely resemble parts of China (e.g. the Central Plains). Indonesia has more large-scale feedlots due to access to cattle imports and plantation crop feed. Indonesia has experienced more volatile economic conditions over the last two decades and transport operators have to navigate congested roads and shipping across the archipelago. In China, three decades of near double-digit economic growth, vestiges from the central planning era and close business–government relations has led to high levels of investment in transport infrastructure, industry infrastructure (i.e. abattoirs, livestock and food markets) and soft infrastructure (i.e. certification schemes and standards, food safety regulations). While these investments are in many cases too far-sighted and not always utilised, they do lay the platform for broad-based industry development.

The beef industries of both countries are major sources of livelihoods for very large numbers of farmers, traders, slaughter workers and beef stallholders in rural and peri-urban communities. Beef also plays a special part in diets for social, religious or ethnic reasons. Industrialisation, labour mobility and resource constraints have exerted supply-side constraints in both countries. Price alignments have increased imports. The Indonesian industry is far more integrated into and exposed to international cattle, beef and currency markets but both countries have signed up to international trade agreements. While there is a demand for imported cattle and beef from most industry stakeholders, governments retain mercantilist trade perspectives as a product of history, resources and demographics and as an interpretation of food security strategies. Both countries have sought to proactively develop their industries, although strategies vary. China is tending away from direct intervention in beef, but retains some traditional storage/price stabilisation mechanisms that are not available in Indonesia.

ACKNOWLEDGEMENTS

The authors would like to thank Zhang Cungen, Zhao Yutian, Dahlanuddin, Lawrence Crissman, Atien Priyanti, Rob Cramb, Tedi Kristedi and Simon Quigley for comments and data.

REFERENCES

BPS (Badan Pusat Statistik) (2011) *Nusa Tenggara Barat Dalam Angka* (Nusa Tenggara Timur in Figures). BPS, Jakarta.

Brown C, Longworth J, Waldron S (2002) *Regionalisation and Integration in China: Lessons from the Transformation of the Beef Industry*. Ashgate, Aldershot.

China Livestock Yearbook (various years) *China Livestock Yearbook*. China Agriculture Publishing House, Beijing.

Deblitz C, Kristedi T, Hadi PU, Triastono J, Puspadi K, Nasrullah (2011) *Benchmarking the Beef Supply Chain in Eastern Indonesia*. Final Report SMAR/2007/202. Australian Centre for International Agricultural Research, Canberra.

Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C (1999) *Livestock to 2020: The Next Food Revolution*. FAE Discussion Paper 28. International Food Policy Research Institute, Food and Agriculture Organization of the United Nations/International Livestock Research Institute, Washington DC.

DGLAHS (various years) Statistik Peternakan dan Kesehatan Hewan (Livestock and Animal Health Statistics). Direktorat Jenderal Peternakan dan Kesehatan Hewan, Jakarta.

Dolberg F, Finlayson P (1995) Treated straw for beef production in China. *World Animal Review* **82**, 14–24.

General Administration of Customs (various years) *China's Customs Statistical Yearbook*. China Customs Press, Beijing.

Hadi P, Ilham N, Thahar A, Winarso B, Vincent D, Quirke D (2002*) Improving Indonesia's Beef Industry.* ACIAR Monograph No. 95. Australian Centre for International Agriculture Research, Canberra.

Hermansyah and Mastur (2008) Pemotongan ternak tidak tercatat, studi di Kota Mataram, Nusa Tenggara Barat. In *Prosiding Seminar Nasional Sapi Potong*, 24 November 2008.

Hutasuhut M, Chang H, Griffith G, O'Donnell C, Doran H (2001) *The Demand for Beef in Indonesia: Implications for Australian Agribusiness*. No. 2001–4. University of New England Working Paper Series in Agricultural and Resource Economics. Graduate School of Agricultural and Resource Economics/School of Economics, December 2001.

Ilham N (2006) Analisis sosial ekonomi dan strategi pencapaian swasembada daging 2010. *Analisis Kebijakan Pertanian* **4**(2), 131–145.

Longworth J, Brown C, Waldron S (2001) *Beef in China: Agribusiness Opportunities and Challenges*. University of Queensland Press, Brisbane.

Mastika I (2003) Feeding strategies to improve the production performance and meat quality of Bali cattle (*Bos sondaicus*). In *Strategies to Improve Bali Cattle in Eastern Indonesia*. (Eds K Entwistle and D Lindsay). ACIAR Proceedings No. 110. Australian Centre for International Agriculture Research, Canberra.

MLA (2012) Indonesia market update. MLA Market Information, Meat and Livestock Australia, August 2012.

MoA and BPS (2011) *Release of 2011 PSPK Final Result*. Ministry of Agriculture/Central Statistics Agency, Republic of Indonesia.

MoA (various years) *Buletin Analisis Perkembangan Harga Komoditas Pertanian*. Pusat Data dan Sistem Informasi Pertanian, Departemen Pertanian.

Morey P (2011) *The Indonesian Cattle and Beef Industries*. Morelink Asia Pacific.

Nason J (2012a) Live export trade rocked by new 5pc import tariff. *Beef Central* 18 July. <www.beefcentral.com/live-export/article/1919>.

Nason J (2012b) Indo FMD-risk: scaremongering or genuine biosecurity threat? *Beef Central* August 31. <www.beefcentral.com/p/news/article/2105>.

National Bureau of Statistics (various years) *China Statistical Yearbook*. China Statistics Publishing House, Beijing.

Poppi D (2009) *Improving Reproductive Performance of Cows and Performance of Fattening Cattle in Low Input Systems of Indonesia and Northern Australia*. Project proposal, Australian Centre for International Agricultural Research, Canberra.

Prabowo H (2011) *What's Up with Beef?* Centre for Indonesia Veterinary Analytical Studies. Posted 9 September 2011. <www.civas.net/content/what%E2%80%99s-beef>.

Priyanti A, Mahendri I, Cahyadi F, Cramb R (2012) Factors affecting the farm-gate selling price of smallholder beef cattle in East Java, Indonesia. Paper presented at the 2012 AAP Animal Science Conference, 26–30 November, Bangkok.

Rutherford A, Tanda P, Fordyce G, Poppi D (2004) Economic analysis of production system interventions. Final Report for Project AS2/2000/103, *Developing an Integrated Production System for Bali Cattle in the Eastern Islands of Indonesia*. Australian Centre for International Agricultural Research, Canberra.

FAOStat (2012) *FAOStat*. Statistics Division, FAO. <http://faostat.fao.org>

Subakti P (1995) *Indonesia's National Socio-Economic Survey: A Continual Data Source for Analysis of Welfare Development*. Central Bureau of Statistics (BPS). <www.rand.org/content/dam/rand/www/external/labor/bps/manualpdf/susenas/surbakti_1995_review.pdf>.

UNComtrade (2012) Commodity Trade Statistics Database. <http://comtrade.un.org>

Vanzetti D, Setyoko N, Trewin R, Permani R (2010) *Home Grown: Cattle and Beef Self-sufficiency in Indonesia*. Working Papers. Crawford School of Economics and Government, Australian National University, Canberra.

Waldron S (2010) *Modernising Agrifood Chains in China: Implications for Rural Development*. Cambridge Scholars Publishing, Newcastle upon Tyne.

Waldron S, Dahlanuddin, Mayberry D, Mulik M, Quigley S, Poppi D (2013) *Eastern Indonesia Agribusiness Development Opportunities: Analysis of Beef Value Chains*. Report prepared by Collins Higgins Consulting Group for Project AGB-2012–005, Australian Centre for International Agricultural Research, Canberra.

Waldron S, Brown C, Longworth J (2003) *Rural Development in China: Insights from the Beef Industry*. Ashgate, Aldershot.

Waldron S, Brown C, Zhang CG (2007) *Update on Developments in the Chinese Cattle and Beef Industry of Relevance to the Australian Industry*. Report prepared for Meat and Livestock Australia.

Winter B (ed.) (2011). *Beef Production in Crop–livestock Systems: Simple Approaches for Complex Problems*. ACIAR Monograph No. 145. Australian Centre for International Agricultural Research, Canberra.

This page intentionally left blank

8 Japanese beef production

M. Komatsu and A.E.O. Malau-Aduli

INTRODUCTION

Unlike countries where most of the beef production systems rely heavily on pastures (e.g. Australia and New Zealand), the limitation of grazing land in Japan restricts beef production to mainly intensive management systems and long-term concentrate feeding. As a result, the relative cost of raising beef cattle in Japan from weaning to finishing is high. Beef cattle herd sizes are smaller in Japan than in many other countries and some of the beef comes as a by-product of the dairy industry where Holsteins are major contributors (~14.6% of national herd). The Wagyu, particularly the Japanese Black, is the predominant national cattle breed (~65.2% of the national herd). Wagyu cattle naturally produce beef with an unmatched level of marbling, unique taste and flavour that commands a traditional sense of pride in Japanese beef consumers.

Japanese animal production (2010) had a gross value of 2552.5 billion yen (AU$1 = 80.985 yen), with 463.9 billion yen attributable to beef production, thus accounting for 31.4% of the gross agricultural production compared to rice (19.1%) and vegetables (27.7%) (MAFF 2012a; Table 8.1). Of the total 354 kt of domestic beef production (subprimal base) in Japan in 2011 (Table 8.2), Wagyu cattle accounted for 45% of domestic beef production (subprimal base), while the remainder was from dairy cattle comprising purebred Holsteins and their crossbreeds with Wagyu (52%), and others (3%) (MAFF 2011; ALIC 2012a; JETRO 2012).

HISTORICAL PERSPECTIVE

The Japanese cattle industry has gone through major changes since the 1950s. During the 1950s and 1960s, mechanised power rapidly replaced the use of cattle and horses for draught. By the mid 1960s, that process was complete. From the late 1960s to early 1970s, selection emphasis was placed on the improvement of native beef breeds, particularly Wagyu cattle. At the same time, the dairy industry developed to the extent that by the mid 1970s it was the principal source of domestically produced beef. The process of structural change in the beef industry accelerated in the 1970s as medium-scale feedlots commenced operation, regional packing plants were established and per capita beef consumption increased (Simpson *et al.* 1985). Economic forces resulted in a major shift by farmers out of cattle husbandry, with associated rapid increases in average herd size. In the mid 1960s, there were 1.4 million cattle farmers, but by 1990 the number had fallen sharply to ~232 000 farmers. The cattle industry, and beef breed cow–calf operations in particular, have played an extremely important role in Japan, mainly by providing an income source for rural people with few other employment alternatives (Simpson *et al.* 1985; Sasaki 2001).

After beef import liberalisation in 1991, beef production from dairy cattle encountered a decline due to the dramatic increase in importation of low-price beef from the USA and Australia: from 353 kt in 1991 to 738 kt in 2000 (Table 8.2). Increased beef imports also supplied new market segments rather than competing directly with domestic beef. Almost all (72%) exports of Australian grass-fed beef and frozen grain-fed beef to Japan in 2012 are utilised in these new segments of the food service sector of the Japanese market. Beef production from purebred dairy cattle shifted to F1 (first cross) or F1 crossbreds from dairy cattle (Chapter 17) in the 1990s because

Table 8.1: Gross animal production in Japan, 2010

Classification	Production outputs (billion yen)	% of GAP	Ratio of domestic production (%)[1]
Gross Agricultural Production (GAP)	8121.4	100	
Animal production	2552.5	31.4	
Beef cattle	463.9	5.7	42
Dairy cattle	772.5	9.5	67
(Raw milk)	(674.7)	(8.3)	
Pork	529.1	6.5	53
Poultry	735.2	9.1	68
(chicken, egg)	(441.9)	(5.4)	96
Others	51.8	0.6	
Crop production	5512.7	67.9	
Rice production	1551.7	19.1	
Vegetable production	2248.5	27.7	

[1] Ratio of domestic production (%) on a weight basis.
Source: Adapted from MAFF (2012a).

of higher transaction prices of Wagyu crossbred cattle. The numbers of transactions involving crossbred beef calves increased from 10 000 head in 1991 to 80 000 head in 2000 (Table 8.3). On the other hand, Wagyu beef, especially Japanese Black cattle numbers, remained relatively steady for the period 1991–2011, as Japanese consumers continued to enjoy the unique flavours of highly marbled Wagyu beef (ALIC 2012a).

Since 2000, beef production in Japan has dramatically changed, with fewer beef imports and a greater reliance on Australia (Chapters 9, 10), rather than the USA (Chapter 5) as a source of imported beef (Table 8.2) The factors responsible for the change in beef production include 1) foot-and-mouth disease (FMD) incidence in Japan in 2000 and 2010, 2) bovine spongiform encephalopathy (BSE) detection in 2001 (in Japan) and 2003 (in the USA), 3) soaring import prices of feedstuffs in 2007, 2008, 2011 and 2012 (Table 8.4), 4) long-term economic stagnation after 2008, 5) changes in the health consciousness of consumers and diversification of consumer needs for beef (safety, quality and palatability etc.) (Table 8.5) and 6) the Tōhoku earthquake and tsunami, and the Fukushima nuclear accident in 2011.

The occurrences of FMD adversely affected beef production and imports such that from 2000 to 2001 there was a sharp decline from 365 kt to 329 kt, and from 738 kt to 608 kt, respectively (Table 8.2). Transaction prices of beef calf and fattening cattle also decreased from 2000 to 2001 with a Japanese Black calf that cost 388 000 yen in 2000, selling for 334 000 yen in 2001 (Table 8.3). Household consumption of beef also decreased sharply over the same time frame, with annual beef consumption falling from 3.1 kg to 2.3 kg per person (Table 8.5). After 2008, as if to add insult to injury, beef cattle farmers were faced with the problem of a deficit balance due to soaring import prices of feedstuff (Tables 8.4, Table 8.6).

The present situation for Japanese beef production will be described along the following lines:

1. main Wagyu beef producing regions and management of beef cattle businesses in Japan;
2. beef production systems in Japan;
3. performance of Japanese beef cattle;
4. beef quality standards in Japan;
5. hereditary diseases in Wagyu;
6. Japanese beef markets – domestic and import;
7. future trends and constraints.

MAIN WAGYU BEEF PRODUCING REGIONS AND MANAGEMENT OF BEEF CATTLE BUSINESSES IN JAPAN

Wagyu

The historical origin of Wagyu cattle has been described (Sasaki 2001) as originating from a time when there were many small, horned and late-maturing cattle used for draught power in Japan. Their coat colours were quite varied, including brown, black, black and white, but black was the most popular among cattle owners. After the Meiji Revolution (1868) that restored imperial rule,

Table 8.2: Beef production and beef import in Japan, 1991–2011

Year	Domestic	Import	Total ('000)	Ratio of domestic	Import ratios by (AUS:NZ: USA: Others)[1]	Number of feeding households	Number of heads[2]	Comments in Japan[3]
1991	407	353	760	53	(31:2: 66:1)	221	2805	Beef import liberalisation
1994	423	589	1012	42	(33:3: 63:1)	184	2971	
1996	383	611	994	39	(45:4: 48:3)	155	2901	
2000	365	738	1103	33	(46:2: 49:3)	117	2823	FMD (O type) outbreak
2001	329	608	937	35	(47:3: 47:3)	110	2806	BSE outbreak. BSE testing system established
2002	364	534	898	41	(49:2: 45:4)	104	2838	
2003	354	520	874	39	(57:4: 39:0)	98	2805	US BSE outbreak.Ban imposed on beef imports from the USA (Dec.)
2004	356	450	806	44	(91:8: 0:1)	94	2788	
2005	348	458	806	43	(89:9: 0:2)	90	2747	US BSE outbreak. Resumption of beef import from the USA and Canada (cattle <20 months old, based on evidence that specific high-risk materials had been eliminated) (Dec.)
2006	346	467	813	43	(88:8: 3:1)	86	2755	Specific high-risk materials detected in veal imported from the USA (Jan.). All beef imports from the USA banned (Jan.). Resumption of beef import from the USA (cattle <20 months old, conditional upon food safety-based evidence) (July)
2007	359	463	822	44	(82:7: 8:3)	82	2806	
2010	358	512	870	41	(69:6: 19:6)	74	2892	FMD (O type) outbreak
2011	354	516	870	41	(65:6: 24:5)	70	2763	FMD-free country status restored in Japan. 2011 Tohoku earthquake and tsunami, Fukushima nuclear accident (11 March)

[1] Import ratio (%) by partner countries: AUS = Australia; NZ = New Zealand; Others = Canada and Mexico etc.

[2] Beef cattle (Wagyu and others) + Holstein and others + crosses between beef cattle and dairy cattle.

[3] FMD = foot-and-mouse disease; BSE = bovine spongiform encephalopathy.

Source: Adapted from MAFF (2012a, 2011); ALIC (2012a); JETRO (2012); Meat and Egg Division (2010).

Table 8.3: Transaction price and number of transaction of beef calf, and transaction price of fattening cattle of livestock farmers in Japan, 1991–2011

	Beef calf			Fattening cattle	
	Japanese Black	**Crossbred**	**Holstein**	**Wagyu steers**	**Holstein (male)**
Year	**(1000 yen/head ('000 head))**			**(1000 yen/10 kg liveweight)**	
1991	471[1]	230[3]	137[4]	12.8[5]	6.3[6]
	(370)[2]	(10)	(36)		
1994	326	126	57	10.9	5.0
	(394)	(27)	(53)		
1996	376	207	112	10.9	5.3
	(336)	(49)	(28)		
2000	388	186	88	10.5	5.0
	(360)	(80)	(16)		
2001	334	158	70	9.0	3.6
	(350)	(73)	(15)		
2002	381	195	69	10.0	3.3
	(371)	(80)	(17)		
2005	488	254	98	13.1	5.0
	(362)	(81)	(18)		
2007	491	212	100	13.0	4.7
	(369)	(84)	(12)		
2009	361	209	88	11.1	4.4
	(388)	(67)	(11)		
2011	399	237	96	11.1	4.1
	(360)	(62)	(8)		

[1] Average transaction price (male + female:♂+♀) (1000 yen/head). Average age, 282–296 days of age; average bodyweight (BW), 272–281 kg.
[2] Number of transaction ('000 head).
[3] Average transaction price (♂+♀). Average age, 219–266 days of age; average BW, 231–291 kg.
[4] Average transaction price (♂+♀). Average age, 199–230 days of age; average BW, 232–270 kg.
[5] 1000 yen/10 kg liveweight.
[6] 1000 yen/10 kg liveweight (at 17–20 months of age).
Source: Adapted from ALIC (2012a).

foreign breeds such as Simmental, Swiss Brown, Devon, Shorthorn and Aberdeen Angus were imported from 1900 to 1908 by the Japanese central government. Many local prefectural governments crossed the foreign breeds with native cattle for genetic improvement of the indigenous breeds. The results were not always successful: crossbred cattle typically had improved growth and development, broad and deep hindquarters and better milking performance, but they were unsuitable for cultivating rice fields and had low meat quality. Farmers began to prefer the small and indigenous cattle again. In order to standardise the conformation and quality of cattle, registration systems were organised in each prefecture around 1918 whereby cattle were selected and uniformity improved. As a result, cattle raised in various prefectures were classified into (mainly) breeds depending on their phenotype and recognised as such from 1948 to 1957. Up to 1955, the number of the Wagyu cattle had increased yearly, but after 1955 cattle numbers decreased dramatically due to modernisation of agricultural practices in which the cattle were no longer used for draught purposes. On the other hand, as the standard of living increased in Japan, Wagyu cattle became increasingly important as beef producers and numbers increased after 1967.

The Japanese Black, Japanese Brown–Kumamoto and –Kochi, Japanese Shorthorn and Japanese Polled are the four cattle breeds (Sasaki 2001) that are indigenous to Japan and collectively called 'Wagyu'. 'Wa' means genial and/or calm, 'gyu' means cattle in Japanese.

Table 8.4: Retail price of assorted feed for beef cattle and import prices of feedstuff and raw materials for assorted feed in Japan, 2000–11

Year	Retail price of assorted feed for beef cattle	Import price (CIF)[1] of feedstuff and raw materials for assorted feed Corn	Barley	Soybean oil meal	Grass hay	Haycube
	(1000 yen per ton)					
2000	45	13	16	26	25	21
2004	52	19	18	36	26	22
2005	52	17	19	33	29	26
2006	54	19	23	31	32	28
2007	63	28	38	42	34	30
2008	70	33	35	50	35	37
2009	59	21	19	44	30	28
2010	58	22	21	39	30	25
2011	62	27	26	37	32	30

[1] CIF = cost, insurance and freight.
Source: Adapted from MAFF (2011); ALIC (2012a).

1. The Japanese Black has a brownish black coat and skin. Wither heights and bodyweights of mature female cattle in average condition are ~130 cm and 474 kg, respectively. They produce excellent meat of high marbling standard (Fig. 8.1a).
2. The Japanese Brown has two sub-breeds. The Japanese Brown–Kumamoto is mainly raised in the Kumamoto prefecture (Fig. 8.1b). The Simmental cattle breed seemed to be largely incorporated in establishing this breed. The features include a brownish yellow or ginger coat, high growth performance and grazing ability. Wither height and bodyweights of mature female cattle in average condition are ~131 cm and 500 kg, respectively.
3. The other sub-breed, Japanese Brown–Kochi, is raised in the Kochi prefecture. This breed was influenced by

Table 8.5: Changes in household consumption and purchase trends for beef meats (domestic and import) in Japan, 1991–2011

	Changes in household consumption (yen or g per capita per year)		Changes in purchase trends (kg/1000 persons/year)			
Year	Yen	Weight (g)	Wagyu beef	Domestic beef (non-wagyu)	Aust. beef	US beef
1991	10 326	3200				
1994	9519	3568				
1996	8713	3206	7.1	8.6	1.2	3.2
2000	7938	3079	1.7	6.6	2.7	3.2
2001	6030	2340	1.5	3.7	3.0	2.0
2002	6577	2498	1.5	4.6	6.0	3.3
2003	6638	2410	1.1	5.2	6.7	2.1
2004	6680	2248	1.6	2.5	8.5	0.0
2005	6672	2244	1.9	2.3	8.9	0.0
2006	6611	2192	1.8	2.4	9.2	0.0
2007	6649	2192	1.9	2.5	9.2	0.1
2008	6586	2150	2.3	3.1	9.0	0.8
2009	6434	2304	2.5	3.0	10.1	1.1
2010	6119	2234	2.6	2.5	9.0	1.5
2011	6011	2217	2.2	2.7	4.6	1.7

Source: Adapted from ALIC (2012a).

Table 8.6: Changes in profitability of beef cattle farmers, 2001–10

Year	Breeding cow		Fattening steers		Fattening dairy steers	
2001	118[1]	[3.5][2]	–67	[–]	–63	[–]
2002	154	[5.6]	17	[0.5]	–99	[–]
2003	181	[7.2]	154	[22.1]	–25	[–]
2004	221	[9.5]	148	[20.6]	57	[21.4]
2005	241	[10.9]	170	[25.4]	65	[29.0]
2006	251	[11.3]	128	[18.6]	43	[16.7]
2007	200	[8.3]	40	[4.4]	–48	[–]
2008	55	[–]	–107	[–]	–59	[–]
2009	36	[–]	–68	[–]	–63	[–]
2010	50	[–]	42	[4.8]	–31	[–]

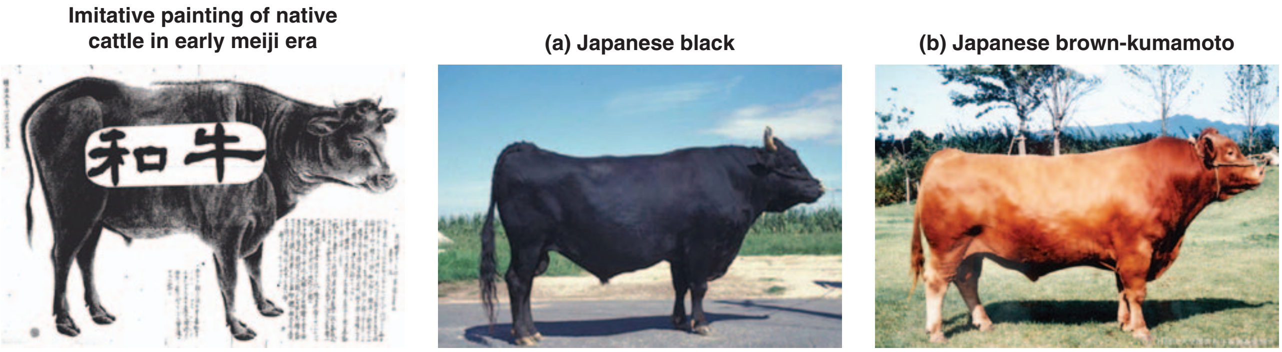
[1] Income (1000 yen/head).
[2] Family labour compensation (1000 yen/day/family).
Source: Adapted from MAFF (2012a).

Korean cattle (Sasaki 2001). The features are a loquat (ginger) coat colour and coat colour separation (called 'Kewake' in Japanese, 'Ke' meaning coat colour and 'wake' meaning separation), i.e. the colours of the eyelids, nasal bridge, nail and horns are black. This feature is characteristic of the breed (Fig. 8.1c). Other features are heat tolerance, good temperament and grazing ability. Wither height and bodyweights of mature female cattle in average condition are ~130 cm and 474 kg, respectively.

4. The Japanese Shorthorn was developed by crossing the indigenous cattle (Nanbu-gyu) with the Shorthorn (meat type and/or dairy type) imported from the USA, England, Canada and Australia in the Meiji to Showa eras in northern Tohoku district and Hokkaido island. This breed is superior in terms of hardiness in a cold climate, grazing ability and roughage intake. Wither height and bodyweights of mature female cattle in average condition are ~132 cm and 571 kg, respectively (Fig. 8.1d).
5. The Japanese Polled is raised in the Yamaguchi prefecture. The population size is very small (~200 head). This breed was developed by crossing the indigenous cattle with the Aberdeen Angus from England. The features of this breed are black coat colour and early maturing. Wither height and bodyweights of mature female cattle in average condition are ~130 cm and 474 kg, respectively (Fig. 8.1e).

Main beef-producing regions in Japan

The number of Wagyu breeds, dairy and dairy crossbreeds (F_1 and F_1 cross) are shown by prefecture in


Imitative painting of native cattle in early meiji era

(a) Japanese black

(b) Japanese brown-kumamoto


(c) Japanese brown-kochi

(d) Japanese shorthorn

(e) Japanese polled

Figure 8.1: An imitative painting of native cattle in the early Meiji era in Japan, plus breeds of Wagyu. (a) Japanese Black. (b) Japanese Brown–Kumamoto. (c) Japanese Brown–Kochi. (d) Japanese Shorthorn. (e) Japanese Polled. Source: NBAFA (2012); Kochi Prefecture (2012); Cattle Museum (1997).

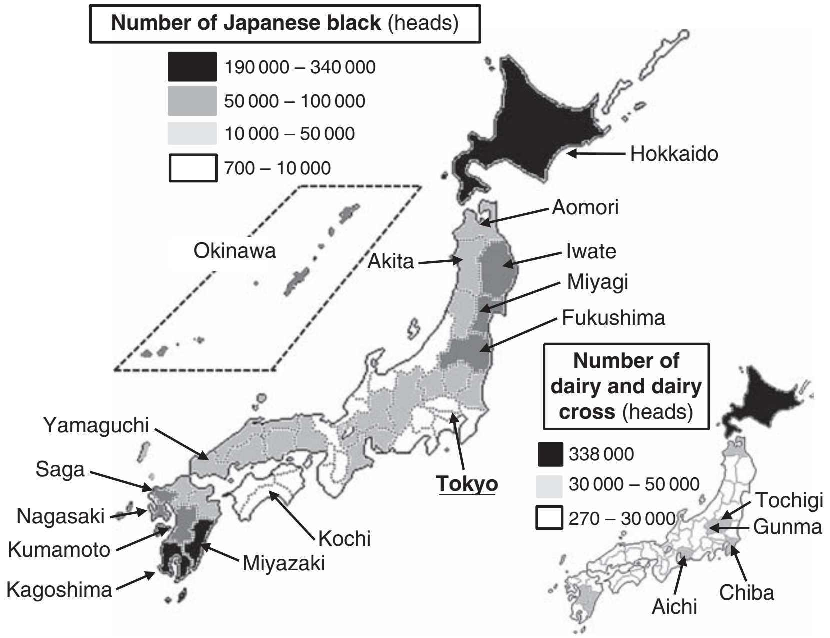


Figure 8.2: Prefectural regions for raising beef cattle. Source: Adapted from MAFF (2011; 2010c).

Table 8.7 and in Fig. 8.2, respectively. The Japanese Black cattle breed has the largest population and accounts for 64% of the beef cattle. They are mainly raised in six prefectures (Kagoshima, Miyazaki, Okinawa, Kumamoto, Nagasaki and Saga) in Kyushu district (47.7% of total number), Hokkaido district (10.3%) and three prefectures (Iwate, Miyagi and Fukushima) in Tohoku district (12.0%). The Japanese Brown–Kumamoto breed is confined mainly to Kumamoto, Hokkaido and Nagasaki prefectures, the Japanese Brown–Kochi is confined to Kochi prefecture and the Japanese Shorthorn is mainly confined to Iwate, Aomori and Akita prefectures. The Japanese Polled is confined to Yamaguchi prefecture and the small population is a result of the beef import liberalisation in 1991. The dairy and dairy crossbreeds account for 33.5% of the beef cattle and are raised mainly in Hokkaido district (34.9% of dairy and dairy crossbreed cattle) and seven prefectures (29.5%: Tochigi, Kumamoto, Aichi, Gunma, Miyazaki, Aomori and Chiba).

Management status of beef cattle business

Cattle are raised by 74 000 farmers; the average herd size has been increasing yearly and averaged 38.6 animals per farmer in 2010 (Table 8.8). The average herd size of beef breeds (28.4 animals per farmer) is smaller than for dairy/dairy crossbreeds (252.4 animals per farmer). Beef calf production and beef fattening are usually segmented. Average beef calf production and beef fattening production is 15.2 and 119.5 animals per farmer, respectively. The total area of forage crop to feed cattle in pens in 2010 was 192 800 ha, and 82.6% of beef cattle farmers have forage crop lands. A further 12.7% of beef cattle farmers graze their animals (in Hokkaido district: 37%). The remaining 4.7% of farmers rely solely on purchased forages and concentrate feeds for raising their beef cattle. Full-time farmers in Japan earned 93% of gross beef production in 2003. From a standpoint of age distribution of beef farmers, 60.9% of the farmers were over 60 years old in 2003. With Japan's ageing population, old age is one of the most serious problems facing beef production.

BEEF PRODUCTION SYSTEMS IN JAPAN

Life-cycles of beef cattle from birth to shipping

The common production patterns of beef cattle are shown in Table 8.9.

Current performance and progeny testing program for Japanese Black bulls

Candidate bulls produced from planned matings are performance-tested in central testing stations (direct testing: six to 12 months of age). Based on their growth, selected young bulls are test-mated with ordinary maiden cows (18 months of age) and their progeny are performance-tested (Sasaki 2001; Takahashi 1985).

Table 8.7: Main beef-producing regions of Wagyu breeds and numbers of beef cattle ('000 head), 2010

Japanese Black regions (prefecture)	No. of animals ('000 head)	Japanese Brown regions (prefecture)	No. of animals ('000 head)	Japanese Shorthorn or Japanese Polled or other breeds regions (prefecture)	No. of animals ('000 head)	Dairy and dairy cross regions	No. of animals ('000 head)
Kagoshima	340 (18.3%)	*Japanese Brown-Kumamoto*		*Japanese Shorthorn*		Hokkaido	338 (34.9%)
Miyazaki	248 (13.4%)	Kumamoto	17.2	Iwate	4.7	Tochigi	52 (5.4%)
Hokkaido	191 (10.3%)	Hokkaido	2.9	Aomori	1.5	Kumamoto	52 (5.4%)
Iwate	90 (4.9%)	Nagasaki	0.8	Akita	1.1	Aichi	44 (4.5%)
Okinawa	84 (4.5%)	Others	2.5	Subtotal	7.3	Gunma	37 (3.8%)
Miyagi	80 (4.3%)	Subtotal	23.4			Miyazaki	35 (3.6%)
Kumamoto	78 (4.2%)			*Japanese Polled*		Aomori	34 (3.5%)
Nagasaki	75 (4.0%)	*Japanese Brown-Kochi*		Yamaguchi	0.2	Chiba	32 (3.3%)
Saga	61 (3.3%)	Kochi	2.6				
Fukushima	52 (2.8%)			*Other breeds* (Aberdeen Angus, Hereford etc.)	37.2	Others	344 (35.5%)
Others	554 (29.9%)						
Total	1853 (100%)		Total 26		Total 44.7	Total	968 (100%)
Total: 2891.7	64%*[1]		0.9% (0.8%, 0.1%)[2]	1.6% (0.3%, <0.0001%, 1.3%)[3]			33.5%[4]

[1] Percentage of Japanese Black. In addition, percentage of Wagyu: 65.2% (= 64% + 0.9% + 0.3% + <0.0001%).
[2] Percentages of Japanese Brown-Kumamoto and Japanese Brown-Kochi.
[3] Percentages of Japanese Shorthorn, Japanese Polled and Other breeds.
[4] Holstein breed 14.6%, crossbreeds 18.9%.
Source: Adapted from MAFF (2011, 2010c); ALIC (2012a).

Table 8.8: Managing status of beef cattle business in Japan, 2010

Management type	Business classification	No. of animals (A)[1] ('000 head)	No. of farmers (B)[1] ('000 houses)	(A)/(B) (heads/ house)
Beef breeds (Wagyu etc.)	Calf production	934	61.4	15.2
	Fattening	729	6.1	119.5
	Consistent (calf – fattening)	283	2.4	117.9
	Others	60	0.8	75
	subtotal	2006	70.7	28.4
Dairy/dairy crossbreeds (Holstein etc.)	Rearing	198	0.64	309.4
	Fattening	525	2.30	228.3
	Consistent (calf – fattening)	130	0.45	288.9
	Subtotal	853	3.38	252.4
	Total	2859	74	38.6
Management status	Working pattern	No. of farmers ('000 houses)	% of gross beef production (yen)	
	Full-time farmer	10.6	93%	
	Semi-full-time farmer	4.8	4%	
	Side business	10.1	3%	
	Total	25.5	100%	
	Organisation management		('000 organisations)	
	No. of organisation		0.8	
% of artificial insemination for cows	99.9%			
% of beef cattle farmers according to age (2003)				
	<50 years old	15.5%		
	50–59 years old	25.2%		
	>60 years old	60.9%		

[1] The number does not include non-profit organisations.
Source: Adapted from MAFF (2012a, 2010c).

The wide-area cooperative progeny testing program was established in 1999 (MAFF 2008). Its purpose was to enhance the genetic improvement of Japanese Black bulls by balancing breeding efficiency and conservation of genetic resources, as described below. The preceding bull improvement system suffered from a lack of selection intensity within each prefectural station, several undetected genetic disorders and inconsistent bull performance evaluation and semen distribution. Therefore, 20 prefectures were engaged in wide-ranging cooperative progeny testing programs and field progeny testing systems were also established (Chapter 17).

The current performance and progeny testing program of Japanese Black bulls has three categories for sire improvement: 1) Livestock Improvement Association of Japan (LIAJ), 2) the wide-area cooperative progeny testing program (20 prefectures) and prefecture-restricted progeny testing program (three prefectures) and 3) commercial breeders (Fig. 8.3) (MAFF 2008). The outline of field systems for progeny testing based on the Wagyu Registry Association is as follows: 1) more than 15 steer or heifer calves (<13 months of age) per sire, 2) reared in several farmers' herds with calves of other competitive candidate bulls, 3) grown for 16–19 months on roughage and concentrate feeds during field testing until evaluation at no more than 29 months of age for steers and 32 months of age for heifers. Based on their own performance and that from progeny testing, Japanese Black bulls are selected at four years of age based on the three criteria as follows: 1) a higher retention ratio of genes of any one of the founders for five specific trait lines ([a] Kinosaki line, ≥5% or [b] Kumanami line, ≥10% or [c] Eikou line, ≥10% or [d]

Table 8.9: Life-cycle of beef cattle from birth to shipping in Japan

Breed	Life-cycle										
	At birth	⇒	Weaning	⇒	First mating	⇒	First calving	⇒	Calving interval	⇒	Second parturition
Japanese Black cows	28 kg body weight (BW)		180 kg BW at 5–6 months		350 kg BW at 16 months		440 kg BW		1–3.3 months		450–550 kg BW
			⇒⇒⇒⇒⇒		Market						
			(continued to 7th parturition)		550 kg BW at 9 years						
	At birth	⇒	Castration	⇒	Weaning	⇒	Fattening start		⇒⇒⇒⇒⇒⇒⇒		Market
Japanese Black steers	30 kg BW		at 2–3 months		at 4 months		290 kg BW at 10 months		Fattening for 20 months		725 kg BW at 30 months
Dairy cattle	At birth	⇒	Castration	⇒	Weaning	⇒	Marketing		⇒⇒⇒⇒⇒		Market
(Holstein) steers	50 kg BW		at 2–3 months		at 3–4 months		260 kg BW at 6 months		Fattening for 16 months		780 kg BW at 22 months

Source: Adapted from MAFF 2012b.

Fujiyoshi line, ≥5% or [e] 38Iwata line, ≥5%), 2) a standard evaluation of genetic performance of station-tested bulls for [a] average daily gain, ≥1.01kg or TDN per 1 kg bodyweight gain, ≤6.1 kg or beef marbling (BMS No.) ≥9.5, [b] the top one-fourth of bulls on breeding values of carcass weight or TDN per 1 kg bodyweight gain or BMS No., and (c) a standard evaluation of genetic performance of field-tested bulls (the top one-fourth of bulls on breeding values or carcass weight or BMS No.) (NLBC 2012).

PERFORMANCE OF JAPANESE BEEF CATTLE

As a result of the sire improvement programs, carcass traits of Japanese Black cattle improved from 2002 to 2010 (NLBC 2010). Carcass weight increased 40 kg for steers (24–35 months of age) and 34 kg for cows (22–38 months of age), rib eye area 3.6 cm^2 for steers and 3.3 cm^2 for cows and beef marbling score number 0.49 units for steers and 0.33 units for cows. Average performances of carcass traits of Japanese Black cattle in 2010 (Table 8.10) and projected

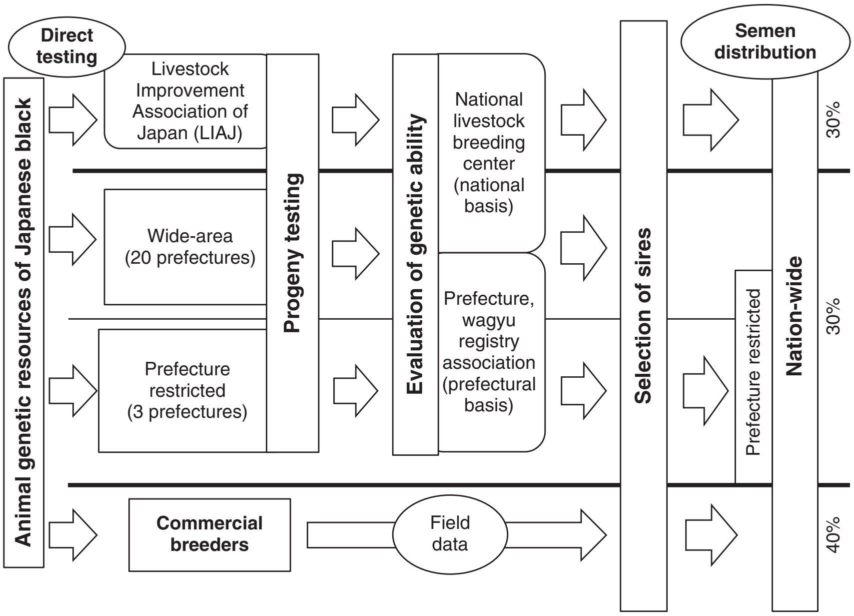


Figure 8.3: Improvement structure for Japanese Black cattle. Source: MAFF (2008).

Table 8.10: Average performance of carcass traits of Japanese Black cattle in Japan, 2010

Sex	No. of animals	Age in days carcass weight[1] (kg/day)	Carcass weight (kg)	Rib-eye area (cm^2)	Rib thickness (cm)	Subcutaneous fat thickness (cm)	Carcass yield estimates (%)	Beef marbling score no.
Steers (24–35 months of age)	~170 000	0.532 ± 0.066	477 ± 57	56.2 ± 8.7	7.76 ± 0.97	2.43 ± 0.75	73.8 ± 1.39	5.76 ± 2.07
Cows (22–38 months of age)	~100 000	0.461 ± 0.061	418 ± 51	54.5 ± 8.7	7.43 ± 0.90	2.75 ± 0.84	73.7 ± 1.46	5.50 ± 2.10

[1] Age in days carcass weight (ADCW) (kg/day) = (carcass weight)/(age in days at slaughter).
Source: NLBC (2010).

performance in 2020 of beef cattle as feeder stock for fattening steers (Table 8.11) indicate genetic progress (MAFF 2010a). The government aims to improve Wagyu's performance by 2020 to grow faster, produce a calf each year and maintain marbling status.

BEEF QUALITY STANDARDS IN JAPAN

Evaluation system for beef carcasses

The left side of a cold beef carcass is cut between the 6th and 7th ribs. After that, the carcass is graded by the Beef Carcass Grading Standard (Japan Meat Grading Association, JMGA 2012). Throughout Japanese meat centres and wholesale markets, the grading of beef carcasses is managed by the JMGA under the approval of the Director, Livestock Industry Department, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries. Carcass grading assists with establishing appropriate production prices and rationalising distribution channels.

Classification of carcass quality is calculated from the cross-section (between the 6th and 7th ribs) of the carcass (Table 8.12). Estimated yield percentage (%) and yield score are calculated using the following equation:

$$\begin{gathered}\text{Yield estimated percentage (YE) (\%)} = 67.37 \\ + (0.130 \times \text{rib eye area (cm}^2)) \\ + (0.667 \times \text{rib thickness (cm)}) \\ - (0.025 \times \text{cold left side weight (kg)})| \\ - (0.896 \times \text{subcutaneous fat thickness (cm)})\end{gathered}$$

Table 8.11: Performance in 2010 and future objective (2020) of beef cattle as feeder stock for fattening steers in Japan

	Breeds	Body weight at the start of fattening (kg) [months of age]		Body weight at the end of fattening (kg) [months of age]		Carcassweight (kg)	Average daily gain (kg)	Meat quality grade
Present (2010)	Japanese Black	285	[9–10]	725	[30]	470	0.72	3.7 (5.7)[3]
	Japanese Brown-Kumamoto[1]	300	[9–10]	730	[25]	465	0.89	2.5 (3.2)
	Japanese Shorthorn	245	[8–9]	745	[25]	450	0.87	2.0 (2.1)
	Dairy breeds	285	[6–7]	750	[22]	435	1.08	2.1
	Crossbreds[2]	270	[7–8]	760	[27]	480	0.84	2.6
Future objective (2020)	Japanese Black	260	[8]	710	[24–26]	460	0.82	3–4 (5.7)
	Japanese Brown-Kumamoto	300	[8]	750	[23]	470	0.99	3 (>3.2)
	Japanese Shorthorn	250	[7]	730	[23]	440	0.99	2 (2.1)
	Dairy breeds	270	[6]	800	[20]	465	1.25	2
	Crossbreds	250	[7]	780	[23]	490	1.09	3

[1] Japanese Brown-Kochi and Japanese Polled included.
[2] Crossbreds are mainly produced by Holstein dam × Japanese Black bull.
[3] Beef marbling score no.
Source: Adapted from MAFF (2010a); NLBC (2010).

In the case of Wagyu carcasses, the intercept value is increased by 2.049 (67.37 + 2.049 = 69.419) to account for higher YE. YE increases in association with an increase in rib eye area and/or rib thickness and decreases in association with an increase in carcass weight and/or subcutaneous fat thickness. Average YE is normally distributed around grade A (>72%) in Japanese Black, grade B (69–72%) in crossbreeds and grades B and C (<69%) in dairy breeds.

Meat quality is evaluated (Table 8.12) according to the following criteria.

1. **Classification of marbling grade.** According to the results of a market survey on carcass distribution by the degree of marbling, the majority was classified in the range of '–1 to 1'. This range is regarded as Grade 3; ~40% of marketed carcasses are included in this grade. Beef marbling is divided into five grades so as to centre around Grade 3. The marbling grades are further divided into 12 Beef Marbling Standard (BMS) grades reflecting continuous change of the degree of marbling. The BMS of average Japanese Black carcass is graded around 5–6, while those of average Japanese Brown–Kumamoto and Japanese Shorthorn are graded around 3–4 and 2–3, respectively (Table 8.11).
2. **Classification of beef colour and brightness of meat.** Meat colour is evaluated against Beef Colour Standards (BCS). The average colour range is from BCS No. 1 to No. 6, which informs a five-point grading system. In contrast, the brightness of meat is evaluated by visual appraisal.
3. **Classification of firmness and texture of meat.** Firmness and texture are evaluated by visual appraisal and used to classify carcasses into five grades.
4. **Classification of beef fat colour and fat lustre and quality.** Fat colour is graded (1–5) using Beef Fat Standards (BFS) prepared as seven continuous standards and visual appraisal of fat lustre and quality. The overall meat quality score is graded down to the lowest grade among the four items described above. Distribution of classification of meat quality in Japanese Black, crossbreed and dairy breed steers in 2010 is shown in Table 8.13.

Carcass quality is finally graded by the yield score and overall meat quality score. In addition, a carcass which is recognised to have any damage is stamped with a superscript mark classified according to the type of damage. Distribution of beef carcass grades in 2011 (JMGA 2012) and wholesale prices of carcass in May 2012 (Statistics Division, Minister's Secretariat 2012) are shown in Table 8.13. Main carcass grades of Wagyu, dairy and crossbreeds are A-4, A-3 (total 56.6%), B-2, C-2 (total 83.9%) and B-3, B-2 (total 69%), respectively. Wholesale prices of carcass vary depending on carcass grade and breeds.

HEREDITARY DISEASES IN WAGYU

There are many hereditary diseases of Wagyu cattle that are detrimental to breeding, health and productive performance (Table 8.14). The gene mutations responsible for the 10 diseases (eight autosomal recessives, one autosomal dominant and one X-linked recessive) were identified through established DNA-based diagnostic systems that have contributed to improvements in Wagyu breeds (Kunieda 2005). Free DNA-based diagnosis of six out of the 10 diseases for sires is used by the National Improvement Association of Japan (NIAJ) for detecting spherocytosis, Factor XIII deficiency, xanthinuria, Chediak-Higashi syndrome, renal tubular dysplasia and multiple ocular defects. The names of affected sires are published regularly by the Ministry of Agriculture, Forestry and Fisheries (MAFF 2012c). The individual carrier frequencies of the six diseases in Japanese Black sires at the National Livestock Breeding Centre and Livestock Improvement Association of Japan varies from undetected to 9.2% (Table 8.14). The highest frequency of carriers is observed in renal tubular dysplasia (LIAJ 2012). It is now possible, using DNA-based diagnostic systems, to reduce the frequency of these mutant alleles in the Wagyu population by using non-carrier sires for mating to produce progeny for the next generation.

JAPANESE BEEF MARKETS: DOMESTIC AND IMPORT

Consumer demand data post 2009 indicated that the Japanese consumed a 1.14-fold more meat (g per day per capita) than fish/ shellfish (FA 2011). Of the 128 million Japanese in 2011, 81 million (63%) were between 15 and 65 years of age and this distribution affected the consumption of animal products. The 40–65 and 13–18 year groups consumed more beef than all the other age groups (Ishibashi 2009). Those that were over 60 years of age (30.2%) consumed more fish/shellfish (FA 2011).

Total beef production and imports in 2011 were 354 kt and 516 kt (subprimal base), respectively (Table 8.2). Beef consumption (demand) was 870 kt, domestic production

Table 8.12: Classification of carcass quality

Division of classes	Meat quality score				
Yield score	5	4	3	2	1
A	A5	A4	A3	A2	A1
B	B5	B4	B3	B2	B1
C	C5	C4	C3	C2	C1

A5 is the most excellent grade, C1 is the worst grade

[I] Yield score

Classification of yield score

Grade	Yield estimated percentage	Specification
A	72% and above	Yield of total cuts above average range
B	69–72%	Average range
C	<69%	Below average range

[II]Meat quality score

(II-1-1) Classification of beef marbling grade

Grade (comments)	Evaluation standard	BMS No.
5 (abundant)	2^+ and above	No. 8 ~ No. 12
4 (slightly abundant)	1^+ ~ 2	No.5 ~ No. 7
3 (moderate)	1^- ~ 1	No.3 ~ No. 4
2 (small)	0^+	No. 2
1 (devoid)	0	No. 1

(II-1-2) The relationship among BMS No., evaluation standard and classification of grade*

BMS No.	Evaluation standard	Classified grade
No. 12	5	5
No. 11	4	5
No. 10	3	5
No. 9	3- (or 2.67)	5
No. 8	2+ (or 2.33)	5
No. 7	2	4
No. 6	2- (or 1.67)	4
No. 5	1+ (or 1.33)	4
No. 4	1	3
No. 3	1- (or 0.67)	3
No. 2	0+ (or 0.33)	2
No. 1	0	1

*The relationship is used for progeny test for carcass performance.

(II-2) Classification of colour and brightness of meat

Grade	Colour BCS No.*	Brightness
5 (very good)	No. 3 ~ No. 5	Very good
4 (good)	No. 2 ~ No. 6	Good
3 (average)	No. 1 ~ No. 6	Average
2 (below average)	No. 1 ~ No. 7	Below average
1 (inferior)	A Grade except Grade5~2	

*BCS: Colour shading [light] No. 1 ←→No.7 [dark]

(II-3) Classification of firmness and texture of meat

Grade	Firmness	Texture
5 (very good)	Very good	Very fine
4 (good)	Good	Fine
3 (average)	Average	Average
2 (below average)	Below average	Below average
1 (inferior)	Inferior	Coarse

(II-4) Classification of fat colour and fat lustre and quality

Grade	BFS No.*	Luster and Quality
5 (excellent)	No. 1 ~ No. 4	Excellent
4 (good)	No. 1 ~ No. 5	Good
3 (average)	No. 1 ~ No. 6	Average
2 (below average)	No. 1 ~ No.7	Below average
1 (inferior)	A Grade except Grade 5~2	

*BFS: Colour shading [bright] No. 1 ←→No.7 [light brown]

An example for classification of carcass quality

Classification of yield score: A → Decision: A-3

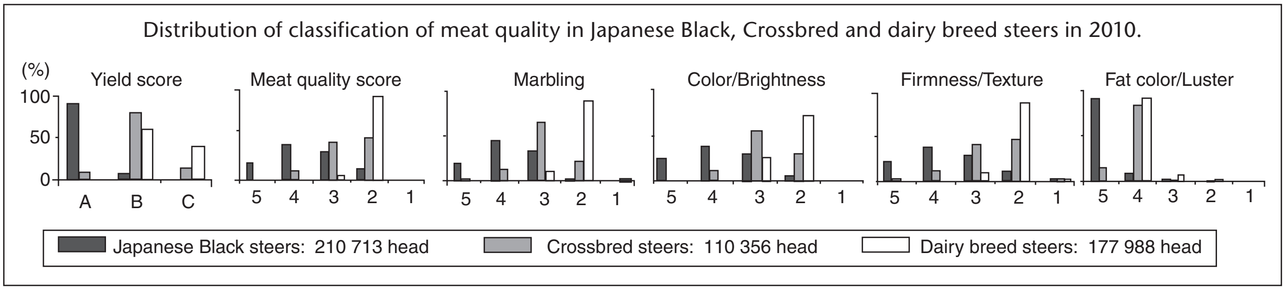
Classification of meat quality score: 3 ←
Classification of marbling: 4
Classification of BCS and brightness: 4
Classification of beef firmness and texture: 3
Classification of BFS and fat lustre and quality: 4

(III) Classification of the type of damage

Type of damage	(Japanese)	Mark
Muscle bleeding (stain)	(Shimi)	ア(A)
Muscle oedema	(Zuru)	イ(I)
Inflammation of muscle	(Shikori)	ウ(U)
External wound	(Atari)	エ(E)
Part missing	(Katsujo)	オ(O)
Others	(–)	カ(KA)

(*Continued*)

Table 8.12: (*Continued*)



Source: JMGA (2012).

was 354 kt and imported beef (supply) was 516 kt in 2011 (MAFF 2012a). Household consumption accounted for 34% of consumption, processed products 5% and institutional use and eating-out 61% (Meat and Egg Division 2010). Consumption (or amount of distribution in the market) of all beef peaked in 2000, while consumption of domestic beef was highest in 1994. Consumption stagnated after the outbreak of BSE in 2001 and 2003, but has been slowly recovering since the lowest level in 2006. In 2010, the Ministry of Agriculture, Forestry and Fisheries set a policy agenda for domestic beef production of 360 kt (subprimal base, estimated from 520 kt of carcass weight base) by 2020 (similar to that of 2010). In addition, it is pursuing policies of planned reorganisation of local small-scale livestock markets and large-scale slaughtering facilities for reducing distribution costs (MAFF 2010b). Imports during 2004 dropped due to the US BSE outbreak in December 2003 and the subsequent ban on imports from that country. The

Table 8.13: Distribution ratio of beef carcass grading (%) in 2011 and carcass wholesale price (yen/kg) in May 2012

Breeds[1]			Grades			Subtotal
	A-5	A-4	A-3	A-2	A-1	
Wagyu	15.5	32.5	24.1	10.3	0.1	81.6
	[2004][2]	[1682]	[1474]	[1137]	[583]	
Dairy breeds	–	–	0.0	0.0	0.0	0.0
			[–]	[813]	[776]	
Crossbreds	0.3	2.7	3.8	1.8	0.0	8.6
	[1374]	[1247]	[1138]	[1037]	[–]	
	B-5	B-4	B-3	B-2	B-1	
Wagyu	0.4	2.7	4.8	7.3	0.7	15.9
	[1810]	[1581]	[1408]	[854]	[605]	
Dairy breeds	–	0.0	2.2	45.2	0.9	48.3
		[–]	[665]	[563]	[353]	
Crossbreds	0.2	6.1	30.9	38.1	0.1	75.5
	[1349]	[1219]	[1108]	[999]	[453]	
	C-5	C-4	C-3	C-2	C-1	
Wagyu	0.0	0.0	0.0	0.6	2.0	2.6
	[1336]	[1281]	[1413]	[549]	[418]	
Dairy breeds	–	0.0	1.2	38.7	11.8	51.7
		[–]	[516]	[494]	[342]	
Crossbreds	0.0	0.3	4.2	10.2	1.1	15.9
	[1039]	[1152]	[1078]	[951]	[433]	

No. of animals: Wagyu = ~0.48 million; dairy breeds = ~0.27 million; crossbreds = ~0.21 million.

[1] Japanese Black, Japanese Brown-Kumamoto, Japanese Brown-Kochi, Japanese Shorthorn and Japanese Polled. Crossbreds are mainly produced by Holstein dam × Japanese Black bull.

[2] Wholesale price: yen/kg, May 2012.

Source: Statistics Division, Minister's Secretariat (2012).

Table 8.14: Hereditary disease in Wagyu

Disease	Clinical symptoms	Hereditary mode	Gene	Cause	Breed[1]	DNA-based diagnosis[2]	Frequency of appearance in sires[3]		Reference
							Carrier		
Spherocytosis	Anemia and icterus	Autosomal recessive	EPB3	A nonsense mutation of the EPB3 gene	J. Black	○	0.6% (4/667)	0.0% (0/667)	Inaba *et al.* (1996)
Factor XIII deficiency	Severe bleeding tendency	Autosomal recessive	F13	A missense mutation of the A subunit of F13 gene	J. Black	○	0.6% (4/667)	0.0% (0/667)	Ogawa (1996)
Xanthinuria	Renal insufficiency	Autosomal recessive	MCSU	A deletion mutation at tyrosine 257 in the MCSU gene	J. Black	○	0.0% (0/65)	0.0% (0/65)	Watanabe *et al.* (2000)
Chediak-Higashi syndrome	Bleeding tendency and albinism	Autosomal recessive	LYST	A missense mutation of the LYST gene	J. Black	○	1.3% (9/667)	0.0% (0/667)	Kunieda *et al.* (1999); Yamakuchi *et al.* (2000)
Renal tubular dysplasia	Renal insufficiency and diarrhea	Autosomal recessive	CL16/ PCLN1	Deletion of the PCLN1 gene (Exons 1–4 were deleted)	J. Black	○	9.2% (61/666)	0.8% (5/666)	Ohba *et al.* (2000); Hirano *et al.* (2000)
Multiple ocular defects	Microphthalmia and eye anomaly	Autosomal recessive	WFDC1	A frame shift mutation of the WFDC1 gene	J. Black	○	1.4% (10/699)	0.0% (0/699)	Abbasi *et al.* (2009)
Factor XI deficiency	Mild bleeding tendency	Autosomal recessive	F11	An insertion mutation of the F11 gene	J. Black	—	—	—	Kunieda *et al.* (2005)
Marfan syndrome-like disease	Normal withers height but lower bodyweight	Autosomal dominant	FBN1	A G>A mutation at the intron 64 splicing acceptor site (a 125 amino acid shorter Fibrillin-1 protein)	J. Black	—	—	—	Hirano *et al.* (2012)
Chondrodysplastic dwarfism	Shortening of limbs	Autosomal recessive	LIMBIN	1) A single nucleotide substitution leading to an activation of cryptic splicing donor site. 2) A one-base deletion resulting in a frame shift mutation	J. Brown -Ku	—	—	—	Takeda *et al.* (2002)
Hemophilia A	Severe bleeding tendency	X-linked recessive	F8	A missense mutation of the F8 gene	J. Brown -Ku	—	—	—	Khalaj *et al.* (2006)

[1] J.Black= Japanese Black; J.Brown-Ku = Japanese Brown-Kumamoto.
[2] Free DNA-based diagnosis of the first six-named diseases for sires is done by National Improvement Association of Japan.
[3] No. of carriers (or deficiency)/total no. of sires tested.
Source: Adapted from Kunieda (2005); MAFF (2012c); LIAJ (2012).

Table 8.15: Export of beef meat and export counterparts

Year	Total (t)	Chilled beef meat (t)				Frozen beef meat (t)			
		Subtotal	Major export partner countries (% share)			Subtotal	Major export partner countries (% share)		
2007	344	217	USA 132 (61%)	Hong Kong 81 (38%)	Vietnam 2.5 (1%)	127	Vietnam 118 (93%)	Malaysia 3.6 (3%)	Hong Kong 2.4 (2%)
2008	550	193	Hong Kong 101 (52%)	USA 86 (45%)	Vietnam 2.7 (1%)	357	Vietnam 336 (94%)	Hong Kong 11.5 (3%)	Malaysia 4 (1%)
2009	675	225	Hong Kong 134 (59%)	USA 78 (35%)	Singapore 26 (12%)	450	Vietnam 431 (96%)	Malaysia 7 (2%)	Hong Kong 5 (1%)
2010[1]	498	234	Hong Kong 192 (82%)	Singapore 19 (8%)	Macau 18 (8%)	264	Macau 98 (37%)	Cambodia 70 (27%)	Vietnam 60 (23%)
2011[2]	580	189	Hong Kong 141 (75%)	Singapore 38 (20%)	Macau 8 (4%)	391	Cambodia 236 (60%)	Macau 89 (23%)	Hong Kong 34 (9%)

[1] Foot-and-mouth disease (O type) infected cattle were found in 2010.
[2] Japan's foot-and-mouth-free status restored.
Source: Adapted from ALIC (2012b).

volumes started to recover from 2005 (Table 8.2). The largest beef import partner country for Japan changed from the USA to Australia in 2001. Australian beef accounted for 65% of imported beef in 2011 (Table 8.2).

Export of beef meats

The ministry now pursues the policies of exporting Wagyu beef to neighbouring countries and developing countries such as Hong Kong, Cambodia and Macau because of

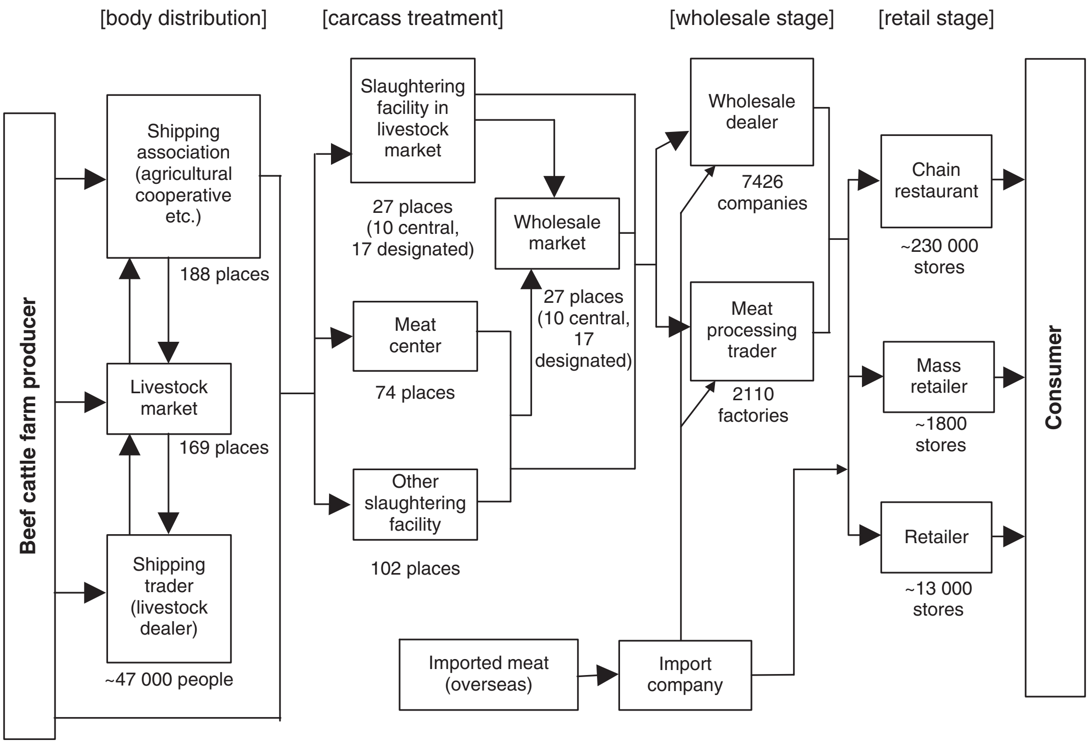


Figure 8.4: Distribution channel of beef from producer to consumer in Japan. Source: Meat and Egg Division (2010).

qualitative changes of food consumption in those countries (Table 8.15). The USA was the major destination of exported beef from Japan until 2009; it banned the import of Wagyu beef because of an incidence of FMD in Japan in 2010. Difficulties in increasing domestic demand for beef due to human population decline and the ageing population highlight the importance of expanding the export base of Wagyu beef to neighbouring and newly developing countries. The expansions are targeted at consumers of niche eating methods (e.g. Shabushabu), and the utilisation of the Wagyu traceability system.

FUTURE TRENDS AND CONSTRAINTS

One of the future trends in Japanese beef production will be changing beef production that emphasises marbling to 'a variety of beef products' in line with diverse consumer needs, e.g. healthy trends towards non-fatty beef and acceptance of the local brand of Wagyu beef. Production of Japanese Black with moderate marbling will be encouraged in Japan. Production of Japanese Brown and Japanese Shorthorn, local breeds that have low marbling and a high grazing ability of locally available feed resources, will also be encouraged as local brand-healthy beef. Establishing distribution channels for these beef products to consumers will be a challenge for Japanese beef production. The other important trend is elucidation of palatability traits of Wagyu meat and the introduction of palatability classification into carcass quality grading. Evaluations of palatability using percentage of monounsaturated fatty acids in intramuscular fat, identification of causal genes for palatability and the diversity of these genes in Wagyu meat are in progress. In addition, the facilitation of distribution rationalisation for cattle and beef, i.e. reorganisation of small-size livestock markets and meat centres, and increase in the rate of utilisation of meat centres (Fig. 8.4), enlargement of self-sufficiency ratio of forage crops and expansion of Wagyu meat export are challenges for Japanese beef production. Finally, early maturity and better feed efficiency (Chapters 15, 18) will be important traits for selecting Wagyu in the future.

REFERENCES

Abbasi AR, Khalaj M, Tsuji T, Tanahara M, Uchida K, Sugimoto Y, Kunieda T (2009) A mutation of the WFDC1 gene is responsible for multiple ocular defects in cattle. *Genomics* **94**, 55–62. doi:10.1016/j.ygeno.2009.04.001.

ALIC (2012a) *Statistical Data: Livestock and Livestock Products*. Agricultural and Livestock Industries Corporation, Tokyo. <http://lin.alic.go.jp/alic/statis/dome/data2/e_nstatis.html>.

ALIC (2012b) *Livestock and Livestock Products*. Agriculture and Livestock Industries Corporation, Tokyo. <http://www.alic.go.jp/livestock/index.html>.

Cattle Museum (1997) *Wagyu: The Origin to a Birth of Brand Beef Cattle*. Cattle Museum, Oshu, Iwate.

FA (2011) *Fisheries of Japan-FY2011 (2011/2012). Fisheries Policy Outline for FY2012 (White Paper on Fisheries:Summary)*. Fisheries Agency, Tokyo. <http://www.jfa.maff.go.jp/j/kikaku/wpaper/h23/index.html>.

Hirano T, Kobayashi N, Itoh T, Takasuga A, Nakamaru T, Hirotsune S, Sugimoto Y (2000) Null mutation of PCLN-1/Claudin-16 results in bovine chronic interstitial nephritis. *Genome Research* **10**, 659–663. doi:10.1101/gr.10.5.659.

Hirano T, Matsuhashi N, Kobayashi N, Watanabe T, Sugimoto Y (2012) Identification of an *FBN1* mutation in bovine Marfan syndrome-like disease. *Animal Genetics* **43**, 11–17. doi:10.1111/j.1365-2052.2011.02209.x.

Inaba M, Yawata A, Koshino I, Sato K, Takeuchi M, Takakuwa Y, Manno S, Yawata Y, Kanzaki A, Sakai J, Ban A, Ono K, Maede Y (1996) Defective anion transport and marked spherocytosis with membrane instability caused by hereditary total deficiency of red cell band 3 in cattle due to a nonsense mutation. *Journal of Clinical Investigation* **97**, 1804–1817. doi:10.1172/JCI118610.

Ishibashi K (2009) Household consumption of beef. *Livestock Industry Information (Chikusan-no-Jyoho)* **6**, 60–67. <http://lin.alic.go.jp/alic/month/domefore/2009/jun/spe-01.htm>.

JETRO (2012). *Foreign Trade Statistics Database*. Japan External Trade Organization, Tokyo. <http://www.jetro.go.jp/cgi-bin/nats/cgi-bin/top.cgi?PGID=000&REP_CNT=0>.

JMGA (2012) *Beef Carcass Grading Standard*. Japan Meat Grading Association, Tokyo. <http://www.jmga.jp; http//www.group.lin.go.jp/kakuduke/>.

Khalaj M, Abbasi AR, Tsuji T, Moritomo Y, Shimojo K, Kunieda T (2006) Polymerase chain reaction-restriction fragment length polymorphism method for identifying carriers of hemophilia A in Japanese brown cattle. *Animal Science Journal* **77**, 122–125. doi:10.1111/j.1740-0929.2006.00329.x.

Kochi Prefecture (2012) Kochi Prefectural Livestock Experiment Station, Sagawa. <http://www.pref.kochi.lg.jp/soshiki/160908/>.

Kunieda M, Tsuji T, Abbasi AR, Khalaj M, Ikeda M, Miyadera K, Ogawa H, Kunieda T (2005) An insertion mutation of the bovine Fii gene is responsible for factor XI deficiency in Japanese black cattle. *Mammalian Genome* **16**, 383–389. doi:10.1007/s00335-004-2462-5.

Kunieda T (2005) Identification of genes responsible for hereditary diseases in Japanese beef cattle. *Animal Science Journal* **76**, 525–533. doi:10.1111/j.1740-0929.2005.00300.x.

Kunieda T, Nakagiri M, Takami M, Ide H, Ogawa H (1999) Cloning of bovine LYST gene and identification of a missense mutation associated with Chediak–Higashi syndrome of cattle. *Mammalian Genome* **10**, 1146–1149. doi:10.1007/s003359901181.

LIAJ (2012) *Genotype Testing for Hereditary Diseases*. Maebashi Institute of Animal Science, Livestock Improvement Association of Japan. <http://liaj.or.jp/giken/kensabu/2ka/main.htm>.

MAFF (2008) *Outline and Assignments of Institutions*. Livestock Industry Department, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries, Tokyo. <http://www.maff.go.jp/j/chikusan/kikaku/lin/index.html>.

MAFF (2010a) *Mission 2020 of Improvement and Increased Production of Livestock*. Ministry of Agriculture, Forestry and Fisheries, Tokyo.

MAFF (2010b) *A Basic Policy for Modernisation of Dairy and Beef Cattle Production in Japan*. Livestock Industry Department, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries, Tokyo. <http://www.maff.go.jp/j/chikusan/kikaku/lin/l_hosin/index.html>.

MAFF (2010c) *Animal Production Statistics 2010 (Heisei 22)*. Department of Statistics, Minister's Secretariat, Ministry of Agricultural, Forestry and Fisheries, Tokyo.

MAFF (2011) *The 85th Statistical Yearbook 2009–2010*. Ministry of Agriculture, Forestry and Fisheries, Tokyo. < http://www.maff.go.jp/e/tokei/kikaku/nenji_e/85nenji/index.html>.

MAFF (2012a) *Trends in Livestock Production*. Livestock Industry Policy Planning Division, Livestock Industry Department, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries, Tokyo. <http://www.maff.go.jp/j/chikusan/kikaku/lin/index.html>.

MAFF (2012b) *3 Beef*. Statistics Department, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries, Tokyo. <http://www.toukei.maff.go.jp/dijest/tikusan/tiku03/tiku03.html>.

MAFF (2012c) *Genotype Testing Results of Hereditary Diseases in Beef Cattle*. Livestock Technology Division, Livestock Industry Department, Ministry of Agriculture, Forestry and Fisheries, Tokyo. <http://www.maff.go.jp/j/chikusan/gijutu/lin/l_katiku/h2402_idensi.html>.

Meat and Egg Division (2010) *Meat Handbook 2009*. Livestock Industry Department, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries, Tokyo.

NBAFA (2012) National Beef Cattle Advancement Fund Association, Tokyo. <http://www.nbafa.or.jp/mame/syurui_kuro.html>.

NLBC (2010) *Outline of the Carcass Traits Performance of Japanese Black Cattle in 2010*. National database of carcass traits of beef cattle. National Livestock Breeding Centre, Nishigo, Fukushima. <http://www.nlbc.go.jp/english/index.html>, <http://www.nlbc.go.jp/pdf/seiseki/edadbgaiyou_h22.pdf>.

NLBC (2012) *Performance Evaluation of Common Use Bulls of the Wide-area Cooperative Progeny Testing Program*. National Livestock Breeding Centre, Nishigo, Fukushima. <http://www.nlbc.go.jp/pdf/identeki/kohyo23s.pdf>.

Ogawa H (1996) Factor XIII deficiency in Wagyu. *Journal of Veterinary Medicine* **49**, 411–412 [Jyui Tikusan Shinpo].

Ohba Y, Kitagawa H, Kitoh K, Sasaki Y, Takami M, Shinkai Y, Kunieda T (2000) A deletion of the paracellin-1 gene is responsible for renal tubular dysplasia in cattle. *Genomics* **68**, 229–236. doi:10.1006/geno.2000.6298.

Sasaki Y (2001) Beef cattle breeding and its trend in Japan. *Asian-Australasian Journal of Animal Sciences* **14**, 111–122.

Simpson JR, Yoshida T, Miyazaki A, Kada R (1985) *Technological Change in Japan's Beef Industry*. Westview Press, Boulder.

Statistics Division, Minister's Secretariat (2012) *Meat Marketing Statistics: Statistics of Agriculture, Forestry and Fisheries*. Ministry of Agriculture, Forestry and Fisheries, Tokyo. <http://www.maff.go.jp/j/tokei/kouhyou/tikusan_ryutu/pdf/niku_1205.pdf>.

Takahashi K (1985) National policy for beef cattle breeding. *Chikusan-no-Kenkyu* **39**, 137–143.

Takeda H, Takami M, Oguni T, Tsuji T, Yoneda K, Sato H, Ihara N, Itoh Y, Kata SR, Mishina Y, Womack JE, Moritomo Y, Sugimoto Y, Kunieda T (2002) Positional cloning of the gene, LIMBIN responsible for bovine chondrodysplastic dwarfism. *Proceedings of the National Academy of Sciences of the USA* **99**, 10549–10554. doi:10.1073/pnas.152337899.

Watanabe T, Ihara N, Itoh T, Fujita T, Sugimoto Y (2000) Deletion mutation in Drosophila ma-1 homologous, putative molybdopterin cofactor sulfurase gene is associated with bovine xanthinuria type II. *Journal of Biological Chemistry* **275**, 21789–21792. doi:10.1074/jbc.C000230200.

Yamakuchi H, Agaba M, Hirano T, Hara K, Todoroki J, Mizoshita K, Kubota C, Tabara N, Sugimoto Y (2000) Chediak–Higashi syndrome mutation and genetic testing in Japanese black cattle (Wagyu). *Animal Genetics* **31**, 13–19. doi:10.1046/j.1365-2052.2000.00586.x.

9 Northern Australian beef production

H.M. Burrow

HISTORY AND DESCRIPTION OF THE NORTHERN BEEF INDUSTRY

Cattle were first introduced to Australia with European settlement in 1788. Growth in the Australian beef herd was initially slow, but expanded in the late 19th century with the discovery of gold and the advent of refrigerated transport. By 1900, the Australian beef herd was estimated at 8.6 million head (ABS 2005) and extended to most regions of Australia, including very large pastoral holdings in central and northern Australia. The subsequent impact of two world wars and the Depression saw numbers remain comparatively stable for the next 50 years. In 1950, the Australian beef cattle herd was 9.7 million head (ABS 2005).

During the first half of the 20th century, beef production in northern Australia was limited by a lack of effective inland transport systems, a strong (alternative) wool industry in some areas of northern Australia and the poor adaptation of *Bos taurus* breeds of cattle to the stressors of the tropical environments (McDonald 1988). This changed dramatically over the 1950s to 1970s with the emergence of export markets in the UK and the development of major export markets to the USA and Japan when the trade to Great Britain abruptly ended with its entrance to the European Union. After the beef slump of the mid 1970s and the successful eradication of brucellosis and tuberculosis, there has been an extraordinary expansion of Brahman and Brahman-derived cattle in northern Australia since the 1980s (Bindon and Jones 2001).

Cattle numbers peaked at ~33 million in 1976. Since then, cattle numbers have fluctuated with climatic conditions and world beef prices (ABS 2005).

In this chapter, Northern Australia is defined as comprising northern Western Australia (WA), the Northern Territory (NT) and Queensland (Fig. 9.1) to ensure consistency with statistical information provided by organisations such as the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). Based on ABARES 2009–10 figures, 59% of the Australian cattle herd was located in northern Australia and 76% of total live cattle exports originated there. The gross value of production of the northern Australian herd was $3.7 billion with value-added beef processing contributing an additional $1.3 billion, giving a total northern beef industry gross value of $5.0 billion for 2009–10 (Gleeson *et al.* 2012).

Traditionally the pastoral industry in northern Australia was characterised by low-input, low-output beef enterprises subject to a harsh and variable climate, uncertain markets and variable prices. However, beef production systems in northern Australia have changed rapidly since the cattle slump of the mid 1970s. The major drivers of change include:

- disease eradication, primarily the brucellosis and tuberculosis eradication (BTEC) scheme that assured Australia's freedom from cattle-borne infectious diseases which posed human health risks and potentially limited export market access. Brucellosis also had the potential to severely affect reproductive performance in breeding herds (Lehane 1996). In addition to freedom from disease, the BTEC scheme provided other benefits for northern beef herds, which were required to develop fencing and water infrastructure for improved handling and control of cattle. These

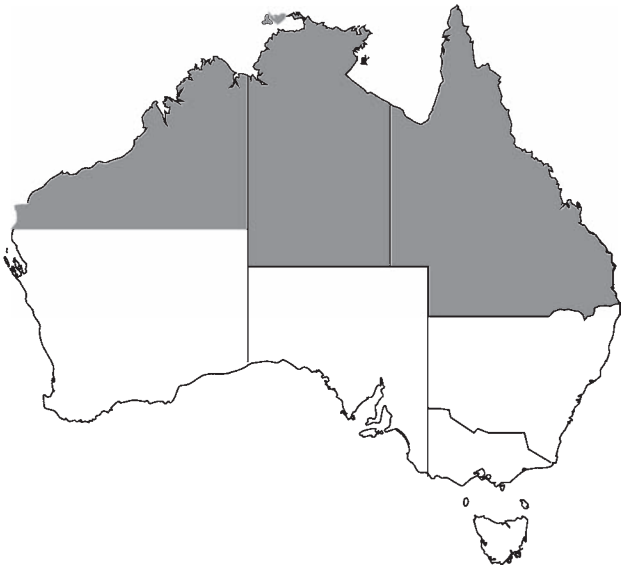


Figure 9.1: Area (shaded) defined as 'northern Australia'.

infrastructure developments led to improved herd management. Destocking of breeding cattle and the removal of feral bulls greatly enhanced the spread of genetic change in northern extensive herds. The significant number of slaughterings associated with the BTEC campaign also allowed a more rapid transition to better adapted and more productive *Bos indicus* breeds;

- the infusion of environmentally adapted breeds into northern herds. Farquharson *et al.* (2003) conservatively estimated the cumulative present value of increasing the proportion of *Bos indicus* genes in the northern Australian herd over 30 years from 5% in 1970 to 85% in the 1990s to be $8.1 billion. The value was estimated in terms of improved profit from replacing British breed cows with *Bos indicus* cows and reflected the superior adaptation of *Bos indicus* to the harsh northern production environments. It did not include cost savings achieved by reduction of treatments for parasites and supplements to ensure survival of British breeds;
- the development of the live export trade especially into South-East Asia, ensuring good alternative markets for *Bos indicus*-infused stock from far northern breeder herds. The crisis in the live trade since 2011 is creating major challenges for northern cattle producers as the *Bos indicus* genotypes are forced to enter southern markets to which they are less suited;
- as a result of the improved infrastructure, there was a rapid increase in the use of herd management technologies such as weaning, early weaning, nutritional supplementation and, in some areas, controlled joining to ensure calves were born at an optimal time relative to the wet season;
- development of the Meat Standards Australia scheme (Thompson *et al.* 2008), providing Australian beef producers with a unique value-based payment system for guaranteed beef quality as perceived by consumers;
- improved transportation and communications, which in turn allowed development of strongly integrated large northern cattle operations controlled by corporate agricultural enterprises. As a result, many corporate enterprises in northern Australia now operate specialist breeding, growing/backgrounding, finishing, processing and retailing business units, including development of their own branded beef products, all of which are vertically integrated across the value chain;
- opening of large export markets in Japan and Korea (for high-quality beef) and South-East Asia (for live cattle);
- expansion of lot feeding (Chapter 11), particularly to reliably reduce the age-of-turnoff of sale steers to comply with Japanese and Korean market requirements and, more recently, to ensure better eating quality and to support greater integration of the corporate sector;
- extensive land development aimed at improving the environmental sustainability of cattle production and, more recently, development of principles for better managing and sustaining the resource base;
- increasing land values due in part to alternative land uses such as mining and tourism and the decline of the Australian wool industry, with sheep all but disappearing from the Pilbara area in WA and a major reduction in sheep numbers in Queensland.

These changes have all resulted in significant interdependence of operational aspects of the northern Australian cattle industry, both geographically and across the various stages of the breeding, growing and finishing production cycles (AusVet 2006). As a result, more individual producers have become specialised in one or two facets of production according to their mix of natural resources, proximity to end markets and management skills (Whan *et al.* 2006).

STRUCTURE OF THE NORTHERN BEEF INDUSTRY

Production sector

Beef producers in northern Australia generally operate more extensive pastoral enterprises than their

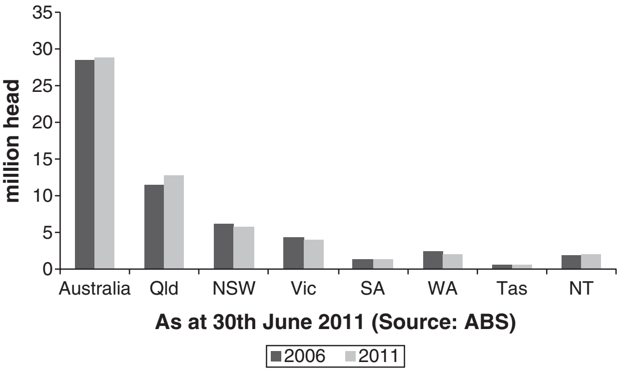


Figure 9.2: Australian cattle herd in recent census years. Source: McRae (2012).

counterparts in southern Australia. In 2005–06, producers in northern Australia accounted for nearly 70% of the Australian beef cattle herd (ABARE 2006).

In June 2011, the Australian Bureau of Statistics (ABS) undertook its five-yearly national census and reported that the Australian cattle herd (including dairy cattle) comprised 28.81 million head, similar to the 2006 census year figure of 28.39 million head (Figs 9.2, 9.3). Of particular note was the growth of the cattle herd in Queensland and the NT between census years (Fig. 9.2), emphasising the continuing growth of the northern Australian cattle herd (Fig. 9.4). In 2006, Queensland and the NT accounted for 47% of Australia's total cattle herd, while in 2011 this had grown to 52% of the national herd or 14.85 million head. In contrast, NSW and Victorian cattle numbers fell 6% and 8% respectively since 2006, with competition from other farming enterprises partly contributing to the decline in herd numbers in southern Australia (McRae 2012).

AusVet (2006) identified seven unique regions of northern Australia based on beef production intensity, climate and topography, with complementary production sectors according to different enterprises and degrees of specialisation. To a very large extent, these regions are based on the boundaries of the statistical regions used by ABARES for collecting farm survey data. Those regions and production systems are (AusVet 2006):

1. **Far North** – the region north of the 15th parallel including the Kimberley, far Top End and northern Cape York; this region has a difficult environment due to rough country, unimproved low-nutrient grasses, heavy tick infestation and poor infrastructure; Brahman cattle predominate, with steers usually marketed to the live export trade; herd sizes range from very small marshalling depots to 25 000 breeders, with an average herd size of 3000 breeding cows; around 60% of enterprises focus on breeding and growing with the remaining 40% focused on specialised growing and backgrounding primarily for the live export trade;
2. **Lower North** – comprises the central Kimberley and NT, upper Gulf and lower Cape York (broadly between the 15th and 20th parallels) and is highly specialised in cattle production; due to harsh conditions and ticks, the cattle have to be highly adapted to be productive; corporate ownership is important in this region and results in clear differentiation between specialised breeding for finishing in the south among the corporates and breeding/growing for live export among family-owned enterprises; Brahmans predominate although crossbreeding and composites are also

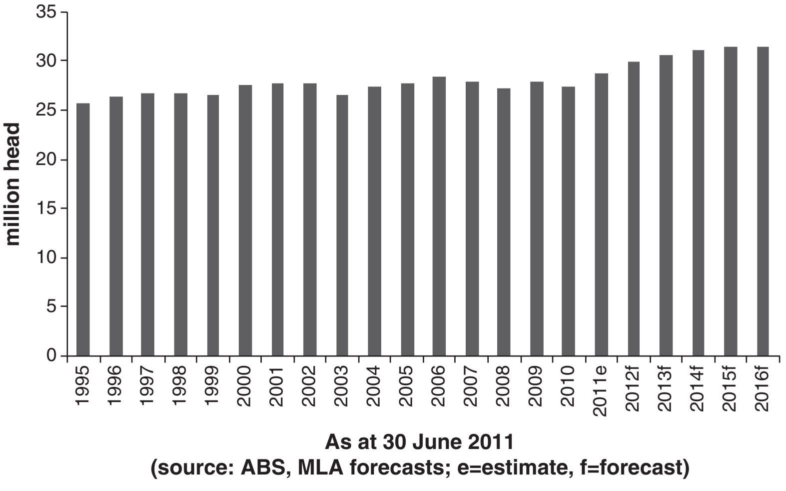


Figure 9.3: Changes in the Australian cattle herd since 1995. Source: McRae (2012).

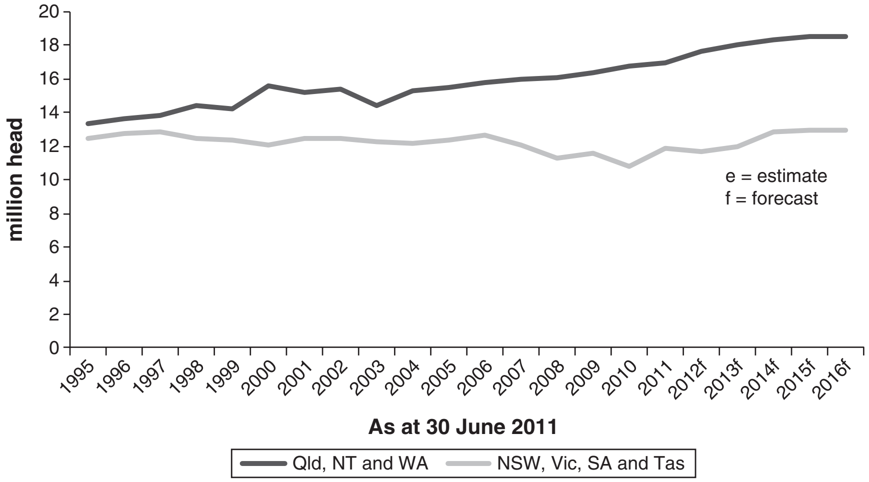


Figure 9.4: The Australian cattle herd continues moving north. Source: McRae (2012).

important; herd sizes range from 3000 to 15 000 breeders, with an average herd size of 7000 breeding females; 20% of businesses in this region are specialist breeding enterprises, 50% breed and grow cattle while the remaining 30% breed and finish cattle;

3. **Arid Zone** – this region accounts for almost half of continental Australia with extensive cattle production occurring over most of the region; in tick-free areas, British breeds predominate though Brahman-cross cattle are also popular for heat and drought tolerance; several subregions can be identified, including the Channel Country in south-west Queensland which is an important cattle growing and finishing region following big wet seasons in the north, when the Channel Country experiences wide, slow floods that result in high-protein cattle feed; cattle turnoff is possible for eight to nine months of the year from this area, though high temperatures prevent cattle work over summer months; the mean herd size is ~1500 head, with an estimated range of 600 to 10 000 head. Other subregions include the Alice Springs region in central Australia and the Pilbara in WA. Stocking rates are naturally very low and drought occurs frequently, but in average to good years, productivity and weight gains can be equal to those achieved in best grazing areas of northern Australia;
4. **Barkly Tableland** – covers an area of ~500 000 sq km of tree-less plains of north-western Queensland and central NT; it is primarily a cattle breeding region based on Brahman, Brahman-derived or stabilised composite breeds; herd sizes range from 10 000 to 50 000 breeders, with an average size of 12 000 breeding females; vegetation is dominated by Mitchell Grass (*Astrebla spp.*); rainfall is <500 mm per annum and mostly received between December and March; the stocking capacity of the region is very low and extensive cattle production is the only form of agriculture in the region; land holdings are large (>3000 sq km) and dominated by corporate producers although several independent operations exist;
5. **Eastern Queensland Coast** – except for river valleys and the Queensland Highlands, much of the country available for cattle production is infertile and better suited to breeding and growing than finishing, though ~30% of enterprises in the region breed and finish their cattle; ticks are endemic and Brahman and Brahman-derived breeds are required to cope with ticks and other parasites; year-round turnoff is possible although the feed supply is summer dominant (Figs 9.5 and 9.6);
6. **Central Queensland** – this is the best agricultural region in northern Australia (AusVet 2006), with good soils (by Australian standards) and generally reliable climate; cattle breeding, growing and finishing all occur in this region, with each activity becoming more specialised according to the mix of natural resources and local infrastructure; the northern and eastern fringes of the region are tick-affected and hence require use of tropically adapted breed types though much of the region is tick-free or with low levels of tick infestation, allowing beef producers to select genetics according to market preferences;
7. **Specialist feedlot finishing** – the Darling Downs area of south-eastern Queensland comprises the most intensive livestock area in Australia (AusVet 2006). In this region, cattle are grain-finished for domestic and international markets in feedlots with capacities up to 75 000 head. Maintaining profitability in this sector

requires a high level of integration with breeding, growing and backgrounding enterprises. Markets range from highly marbled Kobe beef (fed for >300 days) to short-fed domestic product (<70 days). Feedlots turn off finished cattle throughout the year to achieve operational efficiency and economics. Providing it is cost-effective, feedlotting has become a preferred method of finishing cattle because it improves the chances of cattle meeting market specifications, especially where meat quality determines unit price. Corporate producers and abattoirs are attracted to feedlot ownership due to its contribution to integration of the value chain.

A significant feature of the Australian beef industry is that corporate agricultural properties make up only 2% of specialist beef properties but they operate 34% of the land devoted to beef production and own 16% of total beef cattle numbers (ABARE 2006). Expressed in another way, ~2000 specialist/corporate beef enterprises generate over 50% of beef production, while ~38 000 smaller enterprises account for the remaining 50%. The majority of these corporate enterprises are located in northern Australia. By way of example, Australia's largest pastoral company, the Australian Agricultural Co., has more than 600 000 head of cattle grazed on 19 cattle stations, two feedlots and three farms across more than 7.2 million ha of land across Queensland and the NT (~1.2% of Australia's land mass; see http://www.aaco.com.au/).

To provide insight into the performance of properties with different scales of operation, beef cattle properties surveyed by ABARES were stratified into different groups based on the size of their beef cattle herd (Table 9.1). Small businesses (up to 400 head) comprised 51% of properties but only a 7% share of cattle and 9% share of cattle sales, whereas the very large enterprises (>5400 head) comprised only 4.2% of properties but 44% share of cattle and 40% share of cattle sales (Table 9.1). These turnoff percentages suggest that small businesses are either more efficient than their larger counterparts or perhaps that smaller enterprises operate in more favourable production environments, thereby incurring fewer mortalities than the corporate enterprises operating in harsher environments. Table 9.2 shows the estimated composition of the herd on those properties at the same date (Thompson and Martin 2011).

Figure 9.5: Brahmans at Belmont Research Station. Photo: courtesy of CRC for Beef Genetic Technologies.

Figure 9.6: Ticks on a poorly adapted British animal. Photo: courtesy of CSIRO Rockhampton.

Bortolussi *et al.* (2005a) undertook an extensive survey of beef production activities from a representative sample of 375 beef businesses across northern Australia during the 1990s. The survey covered 49.2 million ha of land and ~2.4 million cattle. The surveyed properties covered an array of annual rainfall, property and herd size categories. While corporate property structures and multiple property ownership have been historic features of the northern Australian beef industry, the survey results indicated that the level of additional property ownership by private entities may be increasing, with beef enterprises no longer characterised by a single property. Overall, 50% of the survey properties were managed in conjunction with another property (Bortolussi *et al.* 2005a), up from 31% in the 1980s (O'Rourke *et al.* 1992). Corporate producers have generally used additional properties to facilitate specialisation and vertical integration through movements of store cattle and have taken advantage of the associated risk-management strategies allowed by properties in multiple regions.

Table 9.1: Distribution of beef cattle properties in northern Australia by number of cattle at 30 June 2010

Northern Australia	No. of properties	Share of properties(%)	Share of beef cattle(%)	Share of value of cattle sales(%)
<100 head	1871	19.5	1	2
100–200 head	1346	14.1	2	2
200–400 head	1668	17.4	4	5
400–800 head	1530	16.0	7	7
800–1600 head	1403	14.7	13	14
1600–5400 head	1352	14.1	30	29
>5400 head	400	4.2	44	40
Total	9570	100	100	100

Source: Thompson and Martin (2011).

The survey data indicate that additional properties may now serve differing purposes according to the property location. Properties run in addition to North Queensland and northern WA properties appeared to serve the purpose of increasing the scale of production since they were located in the same region, had the same number of production activities and the percentage of properties buying and finishing on pasture increased. Properties run in addition to the Top End NT survey properties illustrated vertical integration of corporate holdings since the associated properties were located in another or multiple regions. However, in the other survey regions the percentage of associated properties with a single production activity was much higher, suggesting some specialisation (Bortolussi *et al.* 2005a).

Feedlot sector in northern Australia

The production cycle of the Australian beef industry has changed over the past three decades with the introduction and expansion of a specialist feedlotting sector in response to demands from domestic consumers who now require a high-quality eating outcome and from international markets that require specifically tailored, consistently high-quality, year-round product (Bindon and Jones 2001). Traditionally Australian consumers have preferred leaner beef while international markets, particularly Japan and Korea, preferred high levels of marbling in their beef. Grain-finishing of cattle therefore emerged in the late 1980s and early 1990s as a major management strategy to achieve the high levels of marbling required by those markets. The emergence of MSA beef and the demand for high-quality beef by local consumers has also seen an increasing trend for short-term lot-feeding at lighter weights and younger ages. Most beef currently being marketed through the large supermarket chains has had a minimum of 60 days on feed.

Since the early 1990s, the feedlot sector has played an increasingly important role in Australia's beef industry. Across Australia, the feedlot industry has a value of production of ~$2.7 billion while employing ~2000 people directly and ~7000 more indirectly (ALFA 2012). In 2009–10, the feedlot sector accounted for 33% of cattle slaughtered (Thompson and Martin 2011).

There are now around 700 feedlots throughout Australia that have undergone voluntary accreditation through the National Feedlot Accreditation Scheme, with

Table 9.2: Estimated beef herd composition on broadacre properties in northern Australia at 30 June 2010

	Calves	1–2 yr replacement heifers	2–3 yr cows	4–6 yr cows	7+ yrs cows	1–3 yr other cattle	4–6 yr other cattle	4–6 yr other cattle	Bulls	Total
Total beef cattle ('000)	2790	1159	1500	2618	1264	2425	203	42	240	21 240
Share of herd (%)	23	9	12	21	10	20	2	0	2	100

Source: Thompson and Martin (2011).

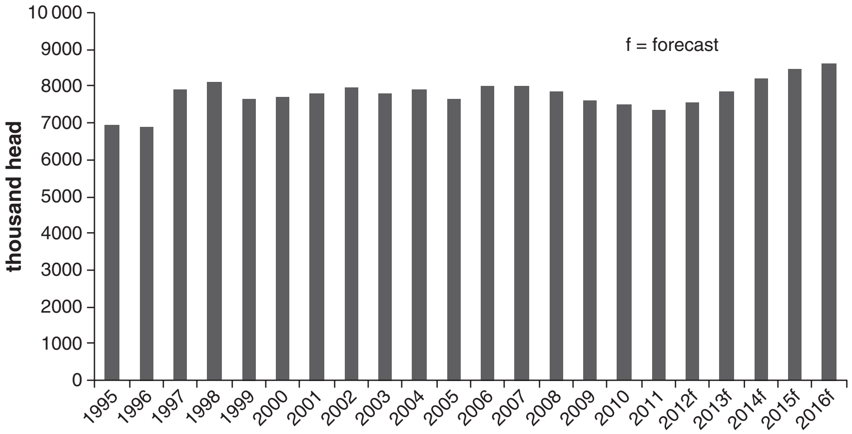


Figure 9.7: Australian adult cattle slaughter since 1995. Source: McRae (2012).

most located in areas in close proximity to cattle and grain supplies (Chapter 11). Northern Australian feedlots are located primarily in south-east and central Queensland. Around 40% of Australia's total beef supply, 80% of beef sold in major domestic supermarkets and the majority of production growth in the Australian beef industry over the last 10 years has been due to the expanding feedlot sector (ALFA 2012; Chapter 11).

Beef processing sector

In Australia, there is an average annual requirement to process ~8 million head of cattle. In the early 1980s, there were 475 plants processing red meat in Australia. By 1990, this number had fallen to 390 and the rationalisation has continued. There are now no operating beef abattoirs north of a geographical line between Townsville in north Queensland and Perth in southern WA, though a new export abattoir near Darwin is under development in 2013.

Attempts by AusVet (2006) to obtain comprehensive aggregated data on the number of cattle slaughtered at individual abattoirs across Australia were not successful because commercial confidentiality has restricted data collection and/or dissemination by industry organisations and government authorities (Fig. 9.7). The only data source identified by AusVet (2006) on abattoir throughput was MLA's publication of the 25 largest meat producing companies in Australia in the magazine *Feedback*. In 2003, those 25 largest companies accounted for ~75% of red meat production across Australia, including major northern Australian beef processing enterprises located on the Darling Downs and in or near Brisbane, Rockhampton, Mackay and Townsville in coastal east Queensland.

MARKETS AND MARKET REQUIREMENTS

Markets for Australian beef influence the profitability of all sectors of the Australian beef industry. But they also have a much broader influence than just profit or loss, as they directly influence herd structure, breed composition, geographical distribution of cattle, production systems (e.g. feedlots, pastures), type and distribution of processing plants, employment and labour requirements and the complexity of retailing and export of beef products (Thompson and Martin 2011).

Northern beef producers sell cattle for slaughter or to other producers for breeding or further growing out (Thompson and Martin 2011). The main market to which producers sell (i.e. abattoir, feedlot, live export, breeders or store) influences the composition of their cattle herds (Table 9.3). Producers who predominantly sell cattle for live export or to breeders or for store purposes tend to sell cattle at a younger age, resulting in fewer non-breeding cattle being retained on-property and proportionally more breeding cows retained in their herds. Hence these properties have the highest proportion of young female cattle, averaging around 25% of their herd. By contrast, producers who predominantly sell cattle direct for slaughter have fewer cows and a higher proportion of young cattle (including calves and other cattle) that are carried for finishing before sale. The herd composition for those targeting feedlots was in line with the national average. However, they tended to have a slightly lower proportion of young female cattle.

In their detailed survey of 375 northern beef properties, Bortolussi *et al.* (2005a) determined the market structure of the enterprise by analysing sales records for the 1991–92 and 1995–96 financial years, based on AUSMeat feedback sheets or other cattle sale records.

Table 9.3: Estimated beef herd composition on broadacre properties in northern Australia at 30 June 2010 by target market

		Calves	1–2 years replacement heifers	2–3 years cows	4–6 years cows	7 years+ cows	1–3 years other cattle	4–6 years other cattle	7 years+ other cattle	Bulls	Total
Direct for	('000)	1447	595	695	1271	583	1450	121	33	112	6307
slaughter	(%)	23	9	11	20	9	23	2	1	2	100
Feedlot	('000)	509	148	188	435	195	329	5	0	40	1849
	(%)	28	8	10	24	11	18	0	0	2	100
Live	('000)	515	241	318	482	337	369	71	7	52	2393
export	(%)	22	10	13	20	14	15	3	0	2	100
Breeders	('000)	307	170	292	413	146	276	6	1	30	1642
or store	(%)	19	10	18	25	9	17	0	0	2	100

Source: Thompson and Martin (2011).

They reported that essentially two different market sectors were available in northern Australia: the live animal and the abattoir markets. The market structures varied widely between regional groups. Store production was most important in central-west, north-west and northern Queensland and the Top End of the NT. The live cattle export market accounted for less turnoff than the store market, except for northern WA. For slaughter cattle, Japan was a significant market for most Queensland regions. Domestic markets were important for coastal central Queensland and Central Highlands properties that have greater opportunities to turn animals off at younger ages, while the Korean market was important for properties in central and southern Queensland. The US market was important for all regions. Queensland regional groups tended to show less specialisation in market aspirations than the northern NT and WA groups. Generally, producers aspired to supply two or three different market weight end-points. These findings remain largely unchanged in 2013.

In addition to the dominant Japanese, Korean and US beef markets, there has been significant growth in beef exports from northern Australia to Russia and more proximate markets in South-East Asia over the past five years (Fig. 9.8; Gleeson *et al.* 2012). Indonesia is now the fifth-largest beef export market. However, Gleeson *et al.* (2012) caution that, while there are opportunities in these emerging markets, they are generally price-sensitive, with strong competition from other suppliers including US exporters. The strongest food demand drivers are rising per capita incomes and urbanisation in developing countries (Delgado *et al.* 1999; 2002), with China becoming an increasingly important beef market for northern Australia. Growth in western-style supermarkets and restaurants is

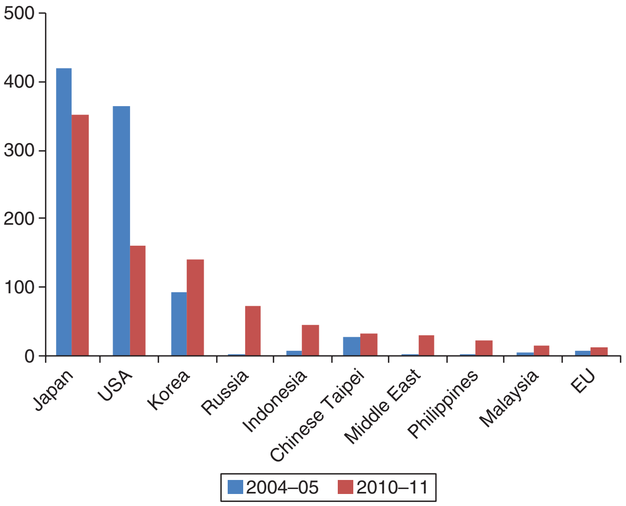


Figure 9.8: Top 10 export markets for northern Australian beef. Source: Gleeson *et al.* (2012).

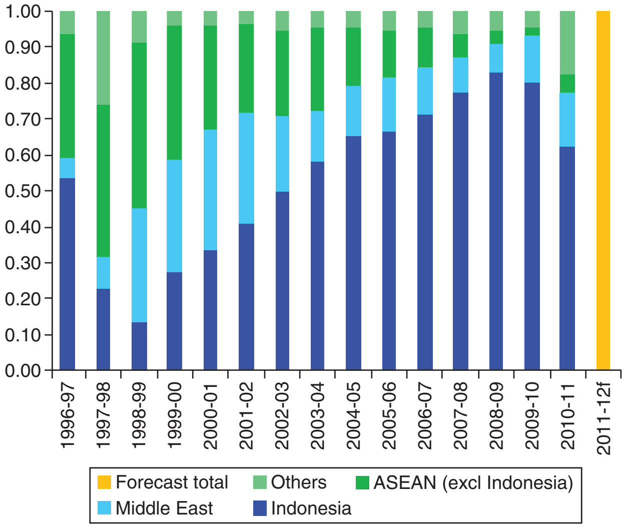


Figure 9.9: Changes in northern Australian live cattle exports. Source: Gleeson *et al.* (2012).

Figure 9.10: Australian Agricultural Co.'s Goonoo feedlot at Comet, Central Queensland. Photo: courtesy of CRC for Beef Genetic Technologies.

adding to the rising demand for beef in China and other developing countries in Asia (Gleeson *et al.* 2012).

Australia's live cattle export markets suffered major damage in 2011 due to exposure of animal cruelty during cattle slaughter in Indonesia (Chapter 12). This resulted in the trade being temporarily suspended. Trade was allowed to gradually resume after a one-month ban, but with strict trace-back of all Australian animals throughout the entire value chain. This has resulted in substantially fewer live animals being exported relative to earlier years (Fig. 9.9). The Indonesian live cattle export market continues to be a risk for northern beef producers due to Indonesia's beef self-sufficiency plans and the fact that breaches of the supply chain assurance system established to allow resumption of the trade may continue to jeopardise the market. Another risk of the live cattle export market highlighted by Bortolussi *et al.* (2005a) is that enterprises turning off younger stock are subject to increased climatic (particularly drought) and market-related risks due to less flexible market options (Holmes 1997).

An increased proportion of breeders in a herd (Table 9.3) represents higher drought risks and requires larger and more intensive management inputs to maintain productivity and manage the risk (Chapters 18, 20). There is also a risk to the natural resource base from breeder herds if overall stocking rates are increased. For example,

Figure 9.11: Brahman heifers at Douglas Daly Research Station, Katherine. NT. Photo: courtesy of Tim Schatz, NT Dept of Resources.

Figure 9.12: Buffalo flies. Photo: courtesy of CRC for Beef Genetic Technologies.

breeder herd productivity and turnoff declines rapidly as stocking rates increase in the NT Victoria River district (Jayawardhana *et al.* 1992). Even though store or live export steer production needs to be significantly more profitable than producing meatworks bullocks to compensate for the higher risks associated with the enterprise (Holmes and Sullivan 1994; Holmes 1997), there are few alternative markets other than the live export market for beef producers in the far north of northern Australia due to the high costs of transport to southern Australia. This suggests that new slaughtering facilities are required in northern Australia or that new live cattle export markets need to be identified in countries such as the Philippines, Malaysia, Vietnam, Brunei, Japan, Egypt, Turkey and Libya, perhaps with the opportunity of exporting breeding cattle and genetics to Indonesia to support its beef self-sufficiency drive (Gleeson *et al.* 2012).

CHALLENGES AFFECTING BEEF PRODUCTION IN NORTHERN AUSTRALIA

Cattle grazed at pasture in northern Australia are subjected to numerous environmental stressors including ecto-parasites (cattle ticks, buffalo flies, other biting insects), endo-parasites (gastrointestinal helminths or worms), seasonally poor nutrition, high heat and humidity and diseases often transmitted by parasites (Chapters 13, 15). The impact of each stressor on production and animal welfare is often multiplicative rather than additive, particularly when animals are already undergoing physiological stress such as lactation (Turner and Short 1972; Turner 1982, 1984; Frisch and Vercoe 1984; Frisch and O'Neill 1998). Under extensive production systems common in northern Australia, it is generally not possible to control the stressors through management strategies alone. Even if intervention strategies were feasible, the treatments often cause their own problems as well as increasing the costs of production. For example, chemical treatments to control parasites generate concern about residues in beef products. As well, the parasites acquire resistance to the chemical treatments, creating additional parasite-control problems (Frisch 2000). In intensive feedlot systems and live cattle exports in northern Australia, high heat and humidity, even in the absence of other stressors, can become critically important for both production and animal welfare reasons. In such cases, management interventions may be possible but are difficult and/or expensive to implement, particularly in poorly adapted cattle. The best method of reducing the impacts of these stressors to improve productivity and animal welfare is therefore to breed cattle that are productive in their presence, without the need for managerial interventions (Burrow 2006, 2012; Chapter 17).

Under climate change scenarios, the impact of these environmental stressors on northern Australian beef producers is likely to increase. For example, White *et al.* (2003) undertook an integrated assessment of the potential impacts of the cattle tick on the Australian beef industry under climate change. A climate-driven, tick population model was run for European, Zebu and crossbred cattle breeds having different levels of resistance to cattle ticks. The abundance of tick populations and reductions in cattle productivity for each breed showed significant increases. Relative to estimates of losses in 2000 of 6594 t per year and in the absence of any adaptation measures, the results indicated changes in the losses in liveweight gain due to cattle tick ranging from 7780 t per year by 2030 to 21 637 t per year by 2100. White *et al.* (2003) noted the principal adaptation options were to use breeds that are more resistant to cattle ticks or to increase the frequency of treatments with tick control products, assuming such treatments retained efficacy and were feasible under the extensive pastoral conditions of northern Australia. The economic advantage of controlling parasites (primarily ticks and worms) of cattle in tropical regions is very dependent on the production system and genotypes (Frisch 2000). As productivity increases by reducing the age at first joining and at slaughter, the production and financial benefits of minimising the detrimental effects of parasites will increase. In the extensive pastoral regions of northern Australia, use of breeds with inherently high parasite resistance avoids many of the problems created by overreliance on chemical control of parasites (Chapter 13).

An increasingly important challenge is meeting the animal welfare standards of domestic and international urban beef consumers who have little knowledge of or interest in the difficulties of beef production in extensive environments. The animal welfare issues faced by the northern Australian beef industry are similar to those faced by extensive livestock production industries in other countries, but they are exacerbated by climatic extremes and large areas and distances (Petherick 2005). These factors, together with low management inputs, means the industry faces significant challenges to ensuring high standards of animal welfare (Chapter 13). Issues that must be considered include natural disasters such as floods, fire and drought; nutrition; animal health; aspects relating to human–animal interactions, particularly mustering and moving cattle and the consequences for welfare of the timing and frequency of handling; surgical procedures; identification; transportation including live export; and feral animal predation (Petherick 2005). The use of cattle adapted to the tropical environment alleviates many potential welfare problems such as ill-thrift and/or mortalities arising from parasite infestation, poor-quality pastures and heat stress due to high temperatures and humidity, all of which are substantially reduced in tropically adapted cattle. In addition, significant improvements to animal welfare could be made very quickly with some relatively straightforward management changes such as improved planning for extended dry periods and drought; wider use of conservative stocking densities and supplementary feeding (Chapter 16); broader implementation of vaccination programs; greater implementation of weaner training programs (Chapter 14); and selection and use of polled genotypes to eliminate dehorning (Mariasegaram *et al.* 2012).

Additional challenges include the need to mitigate the environmental impact of beef cattle by minimising the spread of weeds, reducing methane emissions (Chapter 18); threats to the stability and biodiversity of pastoral ecosystems (Chapter 19); the increasing risk of incursions of devastating exotic diseases (e.g. foot and mouth disease) and parasites (e.g. horn fly) and the consequent loss of preferential access to export markets particularly arising from exotic diseases (Bell *et al.* 2011); lack of transport, processing and shipping infrastructure and year-round access to cattle and infrastructure; water and land security for beef production; and increasing competition for scarce labour resources.

USE OF THE NATURAL RESOURCE BASE FOR BEEF PRODUCTION

Unimproved savannas

The northern Australian beef industry is largely based on utilisation of native pastures (Chapters 15, 16). Maintaining the natural resource base is therefore critical for the continued viability of the industry (Chapter 19). The beef cattle industry is extensive, the productivity of native pastures is low and cattle properties are very large. The rainfall pattern is variable and the threat of droughts a constant source of concern for pastoralists. There are large fluctuations in the size of herds across years, caused by changes in reproduction and mortality rates, which in turn are influenced by climate and the condition of the pastures. Management of the herd size is therefore a compromise between having sufficient cattle in a good season and too many in a drought (Gillard and Monypenny 1990).

Mott *et al.* (1985) suggested that the geographical range of Australia's northern savanna rangelands is limited by the predominantly summer rainfall, soil characteristics and the presence of fire which maintains the balance between grass, tree and shrub. In general terms, low-fertility soils predominate in the north and west. A proportion of high-fertility soils form a mosaic with soils of moderate to low fertility in the east. Because of extensive areas of low-fertility soils in the northern and western parts of the continent, 80% of sown pasture potential and over 95% of crop potential in northern Australia is in eastern and Central Queensland.

Annual variability in rainfall and temperature are the major climatic factors influencing both the reliability and sustainability of beef production. Variation in annual pasture production determines carrying capacity, or with constant animal numbers results in year-to-year variation in utilisation (Mott *et al.* 1985). Diet quality (and hence beef production) is mainly determined by the availability of green leaf (Ash *et al.* 1982; Robbins *et al.* 1987), which is a result of the length of the growing season and frequency of frosts (Chapter 15). Hence, in examining the effect of climatic variation on animal production, both quality and quantity of feed must be considered. For beef cattle production, liveweight gain per animal is linearly related to stocking density (i.e. animals per unit area; Jones and Sandland 1974).

In areas where land clearing was practical (primarily in the higher-rainfall regions of Queensland), the introduction of cattle had a dramatic and often negative effect on the savanna landscape, associated with land clearing to reduce competition between trees and pasture for water and nutrients and to allow greater stocking densities (Ash and McIvor 1998). Combined with overgrazing, this has had particularly negative impacts on fragile tropical rangelands and savannas, which came under increasing pressure after the introduction of *Bos indicus* breeds. However, recent legislation has curtailed land clearing for cattle production and the prospect of the involvement of Australian agriculture in the carbon economy may further offset the drivers for land clearance.

Bortolussi *et al.* (2005d) surveyed the natural resource management practices of 375 northern Australian beef properties across different regions in 1996–97. More than 48% of producers reported land degradation (erosion, salinity, weeds) and over 68% reported woody weeds on their properties. Infestations with multiple weed species were common. Although many producers reported the presence of problem woody weeds, only between 3% and 29% of survey respondents indicated weed management was practised. Property owners who adjusted stock numbers to meet income requirements rather than seasonal variations had a greater tendency to report weeds as a problem on their property. Most producers (67–100%) reported using fire, mostly to reduce rank material and fire risk, to control woody weeds and for grazing management (Bortolussi *et al.* 2005d).

To determine the potential for improvement of the northern savannas, Foran *et al.* (1990) compared eight improved management technologies on a typical beef property carrying ~3000 breeding cows located in the NT Katherine district. Over a 20-year period, the predicted accumulated cash surplus for the superior cow herd supplementation, cow and steer herd supplementation and pasture improvement (with *Stylosanthes* spp.) options were $0.66 million, $1.12 million and $1.32 million respectively. However, after real interest rates of 6% were charged on borrowed capital and company taxation was levied, the 20-year net surpluses were $0.40 million, $0.66 million and $0.35 million respectively. Annual turnoff rates were 24%, 21% and 19% of herd numbers but 33%, 37% and 36% of herd value respectively. These figures compare to an expected 20-year loss of $1.40 million for an undeveloped property in the same area, with a turnoff rate of 14% of herd numbers and 17% of herd value. These results suggest that successful pasture improvement can result in a productive enterprise, but there are major capital investment costs during implementation as well as risks of pasture failure. Hence, nutritional supplementation strategies appear to be more attractive than pasture improvement in the savannas because they require less capital investment and can be suspended in difficult circumstances. However, the values for pasture improvement do not account for the capital appreciation of the land resource and beef producers need to be acutely aware that supplementation without good land management will cause pasture and landscape degradation. Foran *et al.* (1990) concluded that much of the northern Australian beef industry will need to continue to rely mainly on native pastures. They therefore recommended a focus on the long-term maintenance of native pastures rather than their replacement.

Improved pastures and alternative nutrients

The introduction of improved, non-native pasture species (primarily in eastern and Central Queensland) has had a substantial and positive influence on productivity. As indicated by Bell *et al.* (2011), the use of improved pastures has been largely uncontroversial in temperate regions, where improved pastures have been productive and environmentally stable for many decades. However, the introduction of new pasture species in the tropics and subtropics has raised environmental concerns because of their aggressive growth habits and negative effects on native flora biodiversity (Friedel *et al.* 2007).

The Bortolussi *et al.* (2005e) survey reported that a steady stream of introductions of pasture species has been made into northern Australia since 1900, with concerted efforts in research and extension since the 1960s focusing on identification and evaluation of new cultivars and assessing and understanding sown pastures (Gramshaw and Walker 1988; Lonsdale 1994). The benefits of pasture improvement have been widely recognised by beef producers since sown pastures are generally more productive, have higher carrying capacity and support higher growth rates of cattle than native pastures (Winks 1984; Coates *et al.* 1997). However, ~95% of the northern Australian rangelands are still dominated by native pastures (Walker 1991; Clements 1996).

Survey results showed that both tree clearing and killing were more common in Queensland than in the NT or WA. In all regions where trees were killed, native pasture was more widely used than sowing introduced grass and/or legume species. By contrast, tree clearing was most often accompanied by sowing pastures. Killing trees for pasture development was most common in Central Queensland (Bortolussi *et al.* 2005e). The results also showed that a high number of introduced grass and legume species were sown by producers. Most of the sown species were grasses. Many of the sown grass and legume species were spreading naturally. Buffel grass was spreading in all areas with <1000 mm average annual rainfall, but most sown species were spreading only in wetter regions. *Stylosanthes* spp. were the most commonly spreading legume species in regions with >500 mm average annual rainfall (Bortolussi *et al.* 2005e).

Where soil and land types permit, the introduction of combined leucaena (*Leucaena leucocephala*) and improved grass pastures is proving to be one of the most productive, profitable and sustainable improved pasture options for northern Australia. As summarised by Shelton and Dalzell (2007), the rate of adoption of leucaena-grass pastures is rising rapidly as graziers realise the extent of the benefits. According to Shelton and Dalzell (2007), leucaena pastures are suited to >13 million ha of Queensland, with a current estimated 150 000 ha producing 37 500 kg of liveweight gain valued at >$69 million each year. Despite the high costs of establishment, this area is expected to expand to 300 000–500 000 ha by 2017. The main factor driving the high levels of adoption is the ability of leucaena pastures to meet producers' needs for a highly productive and profitable system that meets market requirements for grass-fed beef of superior quality. Production benefits include increased animal production/ha (up to four-fold), resulting from a combination of greater animal liveweight gains and increased carrying capacity, pasture longevity (30–40 yr) and potential to intensify production within the constraints of recent changes to the Queensland Vegetation Management Act and escalating land prices. Other benefits include increased marketing flexibility, superior capital appreciation of leucaena pastures, and positive animal welfare outcomes. Social factors are also important, with many producers in Central Queensland converting marginal dryland cropping cultivation to leucaena pasture owing to concerns about the impact of drought, global warming and decreased profitability and sustainability of dryland cropping. Environmental benefits include dryland salinity mitigation, soil erosion control and improved water quality, improved soil fertility through biological nitrogen fixation, and greenhouse gas mitigation. Given an average season, existing leucaena pastures fix ~7500 t N and reduce cattle methane emissions by ~91 000 t carbon dioxide equivalent carbon (CO_2-e) annually (Shelton and Dalzell 2007). Existing leucaena-based pastures have the potential to annually sequester >4 mt of CO_2-e. However, leucaena is also regarded as an environmental weed in northern Australia, largely due to its historical introduction and use as an ornamental and for slope stabilisation. While most current weed infestations are not due to beef producer plantings, a voluntary Code of Practice, where graziers take responsibility for any spread from their properties, has been developed to limit seed production and dispersal.

In addition to improved pastures, Bell *et al.* (2011) suggested that co-location of intensive beef finishing enterprises could take advantage of new and existing residues and co-products (e.g. sugarcane, banana) in northern Australia. For example, in most years, sugar mills in north Queensland produce more than 1 million t of molasses, of which only ~15–20% is used for stock feed. Research has shown that feedlot diets containing up to 65% molasses as a primary energy source can support bodyweight gains of 1.5 kg/day in Brahman steers with no detrimental effects on cattle health or product quality (Hunter 2012).

BREED COMPOSITION OF THE NORTHERN BEEF HERD

Maximising beef production and profitability requires matching the genotype (breed or crossbreed) to the specific production environment (Chapter 17). Some genotypes are better suited to particular environments. However, in every environment, factors limit beef production, meaning no one genotype is best in all environments. Even though in temperate environments there may be substantial differences in performance between individual breeds, in (sub)tropical areas differences in performance are masked by the effects of environmental stressors on productive attributes. For most purposes in the (sub)tropics, breeds can be categorised into general breed types or groupings (Burrow *et al.* 2001) including:

- *Bos taurus* (British and continental);
- *Bos indicus* (e.g. Brahman, Nellore);
- tropically adapted taurine breeds (southern African Sanga, West African humpless and Criollo breeds of Latin America and the Caribbean);
- tropically adapted indicine *x* British/Continental composite breeds (e.g. Santa Gertrudis, Braford, Charbray);
- tropically adapted taurine *x* British/continental composite breeds (e.g. Bonsmara, Belmont Red, Senepol);
- East African Zebu breeds (e.g. Boran);
- the first cross (F1) between *Bos indicus* and *Bos taurus*, which has attributes that are different from other breed types, particularly in harsher environments.

Comparative rankings of the various breed types for different characteristics in temperate and tropical regions are shown in Table 9.4. In the presence of environmental stressors, productive attributes (growth and fertility) of poorly adapted cattle are significantly reduced relative to their performance in temperate environments or to the performance of adapted cattle in tropical environments. Any breeding program designed for cattle in northern Australia must consider the impacts of both productive and adaptive attributes, even though adaptive traits (and some productive traits) are generally very difficult and/or expensive to measure.

The relative importance of adaptive traits and their impacts on productive traits such as growth (Frisch 1981; Frisch and Vercoe 1984; Turner 1984) and calving rates (Turner 1982) depend greatly on the breed type, the degree of severity of the individual stressor and whether multiple stressors are impacting on performance.

It is difficult to find reliable figures on the precise breed composition of Australia's beef herd. Bindon and Jones

Table 9.4: Comparative rankings of different breed types for productive traits in temperate and tropical environments and for adaptation to stressors of tropical environments

Breed type	***Bos taurus***		**Tropical *Bos taurus***	***Bos indicus***		**F1 Brahman x British**
	British	**Continental[5]**	**Sanga**	**Indian**	**African**	
Temperate[1]						
Growth	****	*****	***	***	**	****
Fertility	*****	****	****	***	****	*****
Tropical[1]						
Growth	**	**	***	****	**	****
Fertility	**	**	*****	***	****	*****
Mature size	****	*****	***	****	***	****
Meat quality[2]	*****	****	*****	***	****	****
Resistance to environmental stressors						
Cattle ticks[3]	*	*	****	*****	*****	****
Worms[4]	***	***	***	*****	****	****
Eye disease	**	***	***	*****	****	****
Heat	**	**	*****	*****	*****	*****
Drought	**	*	*****	*****	*****	****

The more *, the higher the value for the trait.

[1] Temperate environment is assumed to be one free of environmental stressors, while tropical environment rankings apply where all environmental stressors are operating. Hence, while a score of (e.g.) ***** for fertility in a tropical environment indicates that breed type would have the highest fertility in that environment, the actual level of fertility may be less than the actual level of fertility for breeds reared in a temperate area, due to the effect of environmental stressors that reduce reproductive performance.

[2] Principally meat tenderness.

[3] *Rhipicephalus microplus*.

[4] Specifically *Oesophagostomum, Haemonchus, Trichostrongylus* and *Cooperia* spp.

[5] Data from purebred continental breeds are not available in tropical environments and responses are predicted from the CSIRO Rockhampton crossbreeding data.

Source: Burrow *et al.* (2001).

(2001) suggested the most recent estimate of breed composition of the Australian beef herd was presented by ABARE (1998), based on a sample survey rather than a national census. That report indicated that, in 1996–97, 41.5% of Australia's beef herd was Brahman, Brahman-derived or other tropical breed. However, Bindon and Jones (2001) also expressed concern at an apparent increase in the percentage of pure Brahmans in the national herd from 9% in 1990 to 18.2% in 1997. They indicated that this could have been an overestimate based on the survey's definition of pure Brahman, or it could have reflected the influence of the live cattle export trade's expansion, where high-grade Brahmans predominate. This figure could now underestimate the Brahman content of the northern Australian herd. Farquharson *et al.* (2003) suggested the proportion of *Bos indicus* genes in the northern Australian herd had increased from 5% in 1970 to 85% in the 1990s. As suggested by Bindon and Jones (2001), corporate agriculture, through the large northern pastoral companies, had a significant influence on Brahman breed expansion as shown by the fact that Brahman cattle accounted for 18.2% of the national herd in 1996–97 but were confined to only 8% of beef properties.

Regardless of the precise breed composition of the northern Australian beef herd, significant opportunities now exist to both increase market flexibility and improve productivity and profitability of beef herds by reducing their high *Bos indicus* content, while maintaining adequate levels of adaptation to environmental stressors (Burrow *et al.* 2003; Burrow 2012).

PERFORMANCE OF NORTHERN BEEF HERDS

Productivity and profitability

Productivity growth is a key factor determining the profitability of Australian agriculture. The northern Australian beef industry has a strong record of productivity growth over the last five decades, but that growth has slowed dramatically since the 1990s (PMSEIC 2010; Nossal and Sheng 2010). Factors influencing productivity vary between properties, with longer-term influences including the adoption of new technologies and management practices as well as changes in resource condition resulting from degradation (Ha and Chapman 2000). In the short term, seasonal conditions have a major impact. The changed breed composition of the northern beef herd between 1970 and 2000 is likely to have contributed to gains in productivity. Other factors that may have contributed to productivity growth are better marketing of beef, growth in Japanese demand and the growth of the live cattle export trade to Indonesia. Knopke *et al.* (1995) argued that specialist beef producers in northern Australia did not achieve the productivity gains that grain-growers realised over the two-decade (1978–79 to 1998–99) study period primarily because there were fewer changes in production technologies and techniques in the beef industry.

McCosker *et al.* (2010) undertook a situation analysis of productivity and profitability in northern beef production systems to provide baseline data about the economic, environmental and social performance of the industry. In 2009, the industry was in its worst state since the beef slump of the 1970s, with average return on assets of 0.3–2.0%. Average beef producers tended to spend more than they earned in six of the seven previous years, indicating the industry was generally in a very unprofitable and unsustainable situation due to increasing cost of production and overinflated land values. The temporary suspension of the live export trade to Indonesia in 2011 and the reduced, slow resumption of the trade have further exacerbated the situation.

This poor industry position arose for many reasons (McCosker *et al.* 2010), including:

- land values increased significantly, inducing and encouraging higher debt;
- rainfall was below average across Queensland for seven of the previous 10 years and cost of production had consequently risen;
- beef prices generally increased until 2004, then levelled and declined in the last two years of the study period; however, price received was not a consistent driver of the difference between the top 20% and average producers;
- debt levels more than doubled on a per large stock unit (LSU, equivalent to one 400 kg steer with zero liveweight gain) basis over the previous decade;
- legislation around vegetation management impacted development and maintenance options for producers in affected regions;
- scale was a major contributor towards profitability, e.g. Queensland data showed that 1123 LSU were needed at the beginning of the decade to maintain overheads at $80/LSU but at the end of the decade 2405 LSU were needed;
- overheads per LSU rose by 54% and direct costs per LSU rose by 150% over the decade;
- expense ratios (total expenses including interest/gross product) were over 100% in six of the previous seven years for average businesses;
- finance ratios (finance costs/gross product) reached 20% for average businesses, meaning 20% of all income was spent on interest and finance costs;
- the extremely poor reproductive performance of the breeder herd was a major contributor.

However, the top 20% of producers based on return on assets were performing well and matching existing bank deposit rates.

Enterprises turning off younger stock are subject to increased risks due to less flexible market options (Holmes 1997). The younger the age of turnoff of sale cattle, the greater the dependency of enterprise profitability on high reproductive performance of breeding herds (Taylor and Rudder 1986). High *Bos indicus* content cattle have the poorest reproductive performance of all the tropically adapted genotypes grazed at pasture in the tropics. Hence, it is not surprising that, with the increase in Brahman genotypes and the simultaneous reduction in turnoff age at liveweights of <350 kg to the live export market, combined with prolonged drought over much of northern Australia, the profitability of northern beef enterprises is poor. Opportunities to reverse this situation are suggested later in this chapter.

Breeder herd performance and management

The suboptimal reproductive performance of northern herds has only recently assumed prominence because 1) the continuing upgrading of the herd to high-grade Brahman masked the reproductive performance of high-grade Brahmans cf. first-cross Brahman *x* British females and 2) there was a lack of accurate herd recording systems that would assist individual beef enterprises to identify problem animal production areas (Chapters 14, 18). A further difficulty relates to the definition and measurement of annual reproductive performance because year-round joining occurs across much of northern Australia. Even where controlled joining is

Figure 9.13: Tropical composite heifers during the wet season at Toorak Research Station, Julia Creek, north-west Queensland. Photo: courtesy of CRC for Beef Genetic Technologies.

practised, the joining period often extends well beyond the 12-week joining period that allows accurate measurement of annual reproductive performance. Bortolussi *et al*. (2005b) reported the proportion of herds using controlled mating was highest in Central Queensland and the Maranoa south-west region of Queensland, with the mean mating period across all regions varying from 5.6 to 11.8 months.

Ways of defining reproductive performance include pregnancy, calving, branding and weaning rates. But all these measurements are deficient for purposes of annual comparative data. The best definition would be weight of calf weaned per cow joined per annum, but such a measurement is very difficult to achieve in extensive northern beef herds with extended joining periods, particularly when the number of cows joined is often not accurately known. However, northern beef properties should be capable of developing benchmark figures for each business, potentially using a combination of pregnancy and branding rates and ideally recorded on an individual animal basis using the mandatory National Livestock Identification Scheme (NLIS; Price Waterhouse 2006) identification number.

Given the young age-of-turnoff of commercial cattle from most of northern Australia, the animal production issues with greatest impact on profitability of beef breeding enterprises in areas where breeder cow mortality rates are <3%, are delayed puberty, hence delayed first conception of Brahman heifers relative to other breeds, and the failure of many lactating Brahman cows to reconceive with their first calf at foot. In regions of northern Australia where breeder cow mortality rates are high, the biggest impact on profitability is reducing breeder mortality rates (McCosker *et al.* 2010).

Both age at puberty and post partum anoestrus interval in first-calf cows are highly heritable in Brahmans and tropical composites (Johnston *et al.* 2006, 2009, 2010), indicating a genetic approach will be required to overcome these problems (Figs 9.13–9.15). However, the problems are exacerbated in many areas by the harsh environmental conditions, suggesting management approaches must also be implemented to ensure breeding females are reproductively sound at the time of joining. Target pre-joining liveweights and body condition scores of cows needed to achieve targeted pregnancy rates in different breeds and age classes are given by Rudder *et al*. (1985), O'Rourke *et al*. (1991a, b) and Doogan *et al*. (1991) as well as in Chapter 14. Detailed information relating to reproductive performance and mortalities of breeding cattle in specific regions, breeds and/or production systems and underpinning the results presented in these references and Chapter 14 is also summarised by Holroyd and O'Rourke (1989) and Hasker (2000).

Figure 9.14: Brahman cows and calves at Toorak Research Station, Julia Creek, north-west Queensland during the wet season. Photo: courtesy of CRC for Beef Genetic Technologies.

Bortolussi *et al*. (2005b) surveyed breeding herd performance and husbandry on 375 northern Australian beef properties in eight regions during 1996 and 1997. They reported mean branding rates from 62.6% in the NT to 77.1% in the Maranoa south-west region of Queensland, with considerable variation between herds within regions. Calving was seasonal with peak activity in the August–December period. Calving commenced earlier in the south (August) than in northern regions (September–November). Rainfall influenced the time of peak joining and hence calving. The use of pregnancy testing was widespread but selective and often not all females were pregnancy-tested. A majority of producers in all regions indicated their heifers first calved at two to three years of age, though there may have been problems with precisely defining this age as the alternate age at first calving was three to four years. Heifer retention rate was more than 50% in all regions.

About 97% of properties used weaning strategies, most weaning in April–July with a minor peak in September–October. Although mean weaner ages were similar across regions (5.6–6.9 months), mean weaner liveweight varied markedly with weaners in the more northern regions being lightest (<190 kg) while those in southern regions tended to be >200 kg.

Thompson and Martin (2011) reported that branding rates are typically lower and more variable in northern than southern Australia (Fig. 9.16). Branding rates trended upwards in northern Australia from the early 1980s until 1999–2000. Improved livestock genetics and increased herd and disease management (early weaning, breeder supplementation and eradication of brucellosis) have contributed to this result. However, between 1999 and 2006, branding rates trended downwards from their 1999 peak due to a combination of poor seasons and the increasing *Bos indicus* content of the northern herd.

Figure 9.15: Brahman cows at Toorak Research Station, Julia Creek, north-west Queensland during the dry season. Photo: courtesy of CRC for Beef Genetic Technologies.

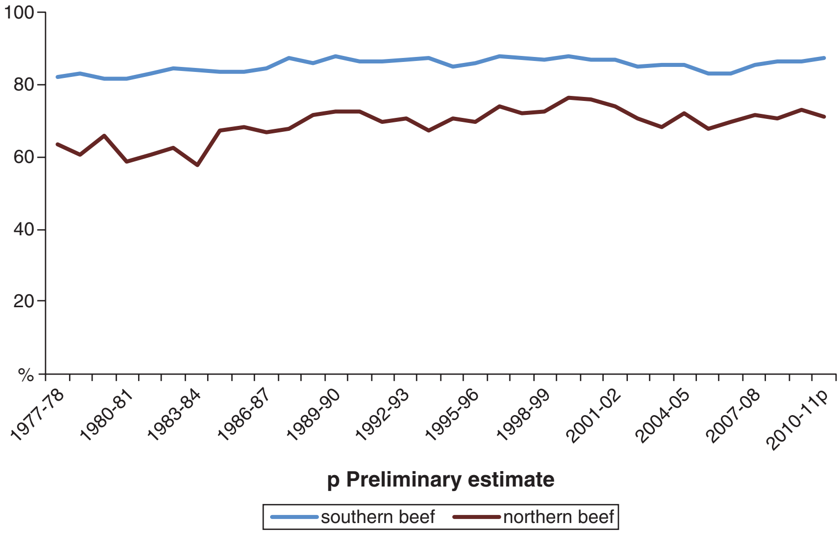


Figure 9.16: Branding rates defined as the number of calves branded as a proportion of cows joined in northern and southern beef herds between 1977–78 and 2009–10. Source: Thompson and Martin (2011).

Holroyd and Fordyce (2001) suggested that a realistic target for weaning rates for adapted cattle in northern Australia in average or better rainfall years is a minimum of 80 calves weaned per 100 cows joined. This may be as high as 90% in extremely good seasons with excellent management. However, a minimum weaning rate should be 70% across a range of years. Swans Lagoon Research Station in the dry tropics of north Queensland achieved a 15-year average branding rate of 83% in cows with 5/8 *Bos indicus* content. Their best-practice management system was based on year-round mating, conservative stocking rates, two annual musters, all calves 100 kg and over weaned at each muster, crisis supplementation, vaccination for botulism and leptospirosis, first joining of heifers at two years, culling of cows at nine years of age, and selection of replacement bulls and heifers using objective performance data.

Growth rates from pasture-based systems

Bortolussi *et al.* (2005c) surveyed 375 northern Australian beef producers and reported mean annual gains for unimproved pasture communities in the more northern regions (black speargrass, brigalow and Mitchell grass) tended to be less than 150 kg/year, whereas liveweight gains for improved pasture species in Central and eastern Queensland were often more than 200 kg/year, particularly with use of hormonal growth promotants (HGP) and/or nutritional supplementation.

Half the survey group used HGPs but use varied between regions, with lowest levels in central coastal Queensland (30%) and highest usage in Central Highlands (59%). Steers and bullocks were the most commonly implanted class of cattle. Supplementation periods tended to be longest in more northern regions. Nitrogen was a component of more than 90% of the supplements offered. The percentage of producers supplementing various classes of cattle varied widely (0–77%). Steers were often the least supplemented class and weaners the most common (Bortolussi *et al.* 2005c).

FUTURE TRENDS, CONSTRAINTS AND OPPORTUNITIES

In coming decades the northern Australian beef industry has a great opportunity to supply beef to a meat-hungry world, particularly to its near neighbours in Asia, but it also faces enormous challenges to capitalise on the opportunity. The world's population is expected to grow by 50% by 2050 (FAO 2007) and world demand for food will grow even more quickly as incomes rise, creating a major opportunity for Australia through growing demand for protein from animal products, particularly in developing countries (Delgado *et al.* 1999; Chapter 1). This represents a major trade opportunity for the northern beef industry.

The biggest challenges for the northern beef industry currently centre on reducing its dependence on a single market (live export to South-East Asia), escalating costs of labour and transport (most of the efficiencies through improved mustering techniques, yard design and stock movement have been realised), low equity levels of individual beef businesses, and a recent significant decline in the capital value of the land.

The increased demand for food will lead to greater competition for inputs such as land, water, grain and labour, driving up the cost of beef production. Climate change is predicted to add to this challenge (Hughes 2003), requiring livestock that are productive under hotter and drier climates and cattle that can tolerate significant increases in ecto- and endoparasitic burdens and vector-borne diseases. There is therefore an urgent need to greatly increase the productivity of cattle herds, but with less grain and water, while the cattle tolerate more extreme climates and disease stressors. Northern beef producers will only be able to capitalise on the opportunity to sell more beef if they remain viable by decreasing their cost of production and achieving significant productivity gains, and if they increase the skill levels of their industry to meet the sector's economic and strategic potential (AgriFood Skills Australia 2011).

In northern Australia, beef production will continue to depend on utilisation of native pastures. Hence, basic issues such as sustaining the pasture resource through correct stocking rates, appropriate paddock sizes, effective cattle control and use of burning and spelling of paddocks are key criteria for sustainable production at an acceptable cost. Deployment of remote monitoring systems for pasture, water and stock management may enhance productivity gains of northern beef herds in future.

Strategies such as heifer management to reduce age at first calving and first-calf reconception rates, early weaning and supplementation of calves to increase liveweight gains of calves and reconception rates of cows, better record-keeping of individual animals for management decision-making, controlled joining, and dry season segregation (and supplementation where required) of different classes of cattle can all improve turnoff rates. As electronic technology develops, it will become possible to link automated data collection of individual animal performance and NLIS identification to enable more effective overall herd and individual animal management. The new technology will potentially overcome some of the problems associated with scarce and unskilled labour in the northern beef industry. The capacity for disease surveillance and response will also be enhanced by the development of NLIS eartags that can identify disease and market-readiness through changes in animal behaviour, movements and remote data collection (Bell *et al.* 2011).

Further productivity gains through genetic improvement, particularly to increase the reproductive performance and market compliance of northern beef herds, can be achieved through greater use of crossbreeding of high-grade *Bos indicus* herds and/or within-breed selection (Burrow 2012). Rates of genetic improvement of northern beef herds are currently much lower than those in southern Australia (Burrow and Banks 2011). The recent advent of genomic technologies provides new opportunities to significantly increase the rates of genetic gain, to optimise management of individual animals or groups of cattle to best meet market specifications and to create value-based marketing systems that reward seedstock and commercial beef producers, feedlots, abattoirs, wholesalers and retailers for delivery of cattle that meet specific market requirements (Chapter 17).

In 2007, a Northern Australia Land and Water Science Review taskforce was established to examine the potential improvement of the Top End of northern Australia. Cribb *et al.* (2009) reported that industry leaders saw great potential to expand sustainable production of beef and cattle by intensifying production. However, this further development depends largely on increased access to abundant fresh water, both surface and groundwater, which at present is severely restricted by water, environmental and pastoral lease conditions, regulations and legislation.

Intensification of the industry was suggested as being based on 'irrigation mosaics' or small-scale, irrigated fodder production and fenced 'stand-and-graze' feeding systems to provide improved year-round access to stock and the ability to finish them during the dry season (Chilcott 2009). In addition to providing improved supply for live export markets, a more evenly distributed supply of better-condition cattle could make abattoirs, such as the new abattoir being developed outside Darwin by the Australian Agricultural Co., economically feasible in the north. The low density of mosaic development, relative to larger-scale irrigation schemes involving fixed assets, enables them to minimise risks associated with the large water volumes and land areas related to such schemes. These include reduced risk of significant groundwater draw-down, salinity, large-scale habitat/function destruction and their inherent lack of flexibility (Chilcott 2009). However as suggested by Gleeson *et al.* (2012), there are other risks to diversifying through irrigation mosaics including the costs exceeding the benefits, potential for unsustainable use and degradation if the hydrology is not well understood and managed, and lack of transport infrastructure to access markets on a year-round basis.

A potential major constraint for the northern beef industry is a carbon tax on methane emissions from cattle. Cribb *et al.* (2009) indicated that the northern cattle industry produces ~4% of Australia's carbon dioxide equivalent emissions so, if fully exposed to a carbon tax, cash income in northern beef properties could decline by up to 20%. Current laws and lease conditions prohibit producers from engaging in carbon offsets and sequestration. If legislation and lease conditions were changed, then Australia's northern pastoral lands could be regenerated for carbon storage as well as for food production and conservation (Cribb *et al.* 2009). Irrespective of whether that opportunity is captured, potentially the best way for the northern beef industry to reduce methane emissions from cattle is to focus on maximising the productivity of their herds, as decreased mortality rates, improved reproductive performance and reduced days-to-market will significantly reduce methane emissions per kg of beef (Howden and Reyenga 1999; Charmley *et al.* 2008; Cottle *et al.* 2011).

A major constraint to development is the lack of infrastructure such as roads, wharves, ports, abattoirs and communications across much of the area and, in particular, the lack of processing facilities to service many regions of northern Australia. Large numbers of northern beef producers are almost totally dependent on a single live-export market for young animals (<350 kg liveweight), with no market for cull cows or bulls. The lack of an abattoir is also a constraint to achieving the full benefits offered by mosaic irrigation (Cribb *et al.* 2009). The solution lies in identifying alternative live export markets, developing more cost-effective transport to southern growing, finishing and/or processing facilities for tropically adapted composite cattle that are well suited to meet the specifications of the high-quality beef markets, and/or establishing meat processing facilities in northern Australia, as currently being investigated by three consortia. However, unless existing production systems change markedly to enable delivery of heavier finished cattle, any new abattoir in northern Australia is likely to face the same problems that forced the recent closure of meatworks in the region, i.e. lack of economies of scale, high wharf costs, poor access to frozen beef markets, seasonality of cattle supply, access only to lower-value cattle, difficulty of attracting skilled labour to remote sites (thereby increasing costs), and inadequate transport infrastructure for both the cattle and end products. Establishing a meat processing plant in the region should, however, encourage development of a feed-on sector and/or a shift to fattening enterprises if it can be supported by sustainable irrigation programs (Gleeson *et al.* 2012). Cribb *et al.* (2009) suggested that corporate agriculture could be a facilitator for such infrastructure development as that sector has access to highly skilled staff capable of scoping infrastructure developments. The sector may also be able to achieve the mass required to attract government co-investment. Corporates involved in beef production have an incentive to invest in infrastructure because it underpins their own business productivity and profitability (Cribb *et al.* 2009).

Ultimately, the future of the northern Australian beef industry requires an unwavering focus on strong business principles at individual enterprise level, with the aim of improving business productivity and profitability and overcoming major global challenges such as climate change and increased competition for inputs, to meet the very significant new trade opportunities being created by a rapidly increasing demand for animal protein by a growing world population.

REFERENCES

ABARE (1998) Australian beef industry 1998. ABARE Research Report No. 98.7. ABARE, Canberra.

ABARE (2006) *Australian Beef Industry.* <http://www.abareconomics.com/publications_html/livestock/livestock_06/ausbeef.pdf>.

ABS (2005) *Year Book Australia, 2005.* <http://www.abs.gov.au/ausstats/abs@.nsf/46d1bc47ac9d0c7bca256c470025ff87/1a79e7ae231704f8ca256f720082feb9!OpenDocument>.

AgriFood Skills Australia (2011) *Australia's Regions: Australia's Future.* Environmental Scan. <http://www.agrifoodskills.net.au/publications/shaping-and-influencing-agrifood/scan-2011/>.

ALFA (2012) Australian Lot Feeders' Association. <http://www.feedlots.com.au/>.

Ash A, McIvor JG (1998) Forage quality and feed intake responses to oversowing, tree killing and stocking rate in open eucalypt woodlands of north-east Queensland. *Journal of Agricultural Science (Cambridge)* **131**, 211–219. doi:10.1017/S0021859698005607.

Ash AJ, Prinsen JH, Myles DJ, Hendrickson RE (1982) Short-term effects of burning native pasture in spring on herbage and animal production in south-east Queensland. *Proceedings of Australian Association of Animal Production* **14**, 377–380.

AusVet (2006) A review of the structure and dynamics of the Australian beef cattle industry. A report to the Australian

Department of Agriculture, Fisheries and Forestry. <http://www.daff.gov.au/__data/assets/pdf_file/0009/723825/dairy-movement-ead.pdf>.

Bell AW, Charmley E, Hunter RA, Archer JA (2011) The Australasian beef industries: challenges and opportunities in the 21st century. *Animal Frontiers* **1**(2), 10–19. doi:10.2527/af.2011-0015.

Bindon BM, Jones NM (2001) Cattle supply, production systems and markets for Australian beef. *Australian Journal of Experimental Agriculture* **41**, 861–877. doi:10.1071/EA01052.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005a) The northern Australian beef industry, a snapshot. 1. Regional enterprise activity and structure. *Australian Journal of Experimental Agriculture* **45**, 1057–1073. doi:10.1071/EA03096.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005b) The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management. *Australian Journal of Experimental Agriculture* **45**, 1075–1091. doi:10.1071/EA03097.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005c) The northern Australian beef industry, a snapshot. 3. Annual liveweight gains from pasture based systems. *Australian Journal of Experimental Agriculture* **45**, 1093–1108. doi:10.1071/EA03098.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005d) The northern Australian beef industry, a snapshot. 4. Condition and management of natural resources. *Australian Journal of Experimental Agriculture* **45**, 1109–1120. doi:10.1071/EA03262.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005e) The northern Australian beef industry, a snapshot. 5. Land and pasture development practices. *Australian Journal of Experimental Agriculture* **45**, 1121–1129. doi:10.1071/EA04013.

Burrow HM (2006) Utilisation of diverse breed resources for tropical beef production. In *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production.* CD-Rom Communication No. 32–01.

Burrow HM (2012) Importance of adaptation and genotype x environment interactions in tropical beef breeding systems. *Animal Special Issue on Sustainable Animal Production in the Tropics* **6**, 729–740.

Burrow HM, Banks RG (2011) Increasing uptake of genetic technologies across the beef value chain. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **19**, 391–398.

Burrow HM, Moore SS, Johnston DJ, Barendse W, Bindon BM (2001) Quantitative and molecular genetic influences on properties of beef. *Australian Journal of Experimental Agriculture* **41**, 893–919. doi:10.1071/EA00015.

Burrow HM, Johnston DJ, Barwick SA, Holroyd RG, Barendse W, Thompson JM, Griffith GR, Sullivan M (2003) Relationships between carcass and beef quality and components of herd profitability in northern Australia. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **15**, 359–362.

Charmley E, Stephens ML, Kennedy PM (2008) Predicting livestock productivity and methane emissions in northern Australia: development of a bio-economic modelling approach. *Australian Journal of Experimental Agriculture* **48**, 109–113. doi:10.1071/EA07264.

Chilcott C (2009) Growing the north: opportunities and threats to developing agriculture in the north of Western Australia. *Farm Policy Journal* **6**, 11–17.

Clements RJ (1996) Pastures for prosperity. 3. The future for new tropical pasture plants. *Tropical Grasslands* **30**, 31–46.

Coates DB, Miller CP, Hendrickson RE, Jones RJ (1997) Stability and productivity of *Stylosanthes* pastures in Australia. II. Animal production from *Stylosanthes* pastures. *Tropical Grasslands* **31**, 494–502.

Cottle DJ, Nolan JV, Wiedemann SG (2011) Ruminant enteric methane mitigation: a review. *Animal Production Science* **51**, 491–514. doi:10.1071/AN10163.

Cribb J, Harper GS, Stone P (2009) Sustaining growth of the northern beef industry. In *Northern Australia Land and Water Taskforce Report.* Chapter 5 5-1–5-30.

Delgado CL, Rosegrant MW, Meijer S (2002) Livestock to 2020: the revolution continues. In *Proceedings of the World Brahman Congress.* Rockhampton, Australia.

Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C (1999) Livestock to 2020: the next food revolution. Food, Agriculture and the Environment Draft Discussion Paper 28. International Food Policy Research Institute, Food and Agriculture Organization of the UN/International Livestock Research Institute.

Doogan VJ, Fordyce G, Shepherd RK, James TA, Holroyd RG (1991) The relationships between liveweight, growth from weaning to mating and conception rate of *Bos indicus* cross heifers in the dry tropics of North Queensland. *Australian Journal of Experimental Agriculture* **31**, 139–144. doi:10.1071/EA9910139.

FAO Commission on Genetic Resources for Food and Agriculture (2007) *The State of the World's Animal Genetic Resources for Food and Agriculture.* (Eds B Rischkowsky and D Pilling) pp. 141–142. FAO, Rome.

Farquharson RJ, Griffith GR, Barwick SA, Banks RG, Holmes WE (2003) Estimating the returns from past investment into beef cattle genetic technologies in Australia. Economics Research Report No. 15. NSW Agriculture. <http://www.agric.nsw.gov.au/reader/18816>.

Foran BD, Stafford Smith DM, Niethe G, Stockwell T, Michell V (1990) A comparison of development options on a northern Australian beef property. *Agricultural Systems* **34**, 77–102. doi:10.1016/0308-521X(90)90095-8.

Friedel M, Bastin G, Brock C, Butler D, Clarke A, Eyre T, Fox J, Grice A, van Leeuwen S, Pitt J, Puckey H, Smyth A (2007) Developing a research agenda of the distribution and rate of spread of buffel grass (*Cenchrus ciliaris*) and identification of landscapes and biodiversity assets at most risk from invasion. Report to the Department of the Environment and Water Resources, December 2007. Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Frisch JE (1981) Changes occurring in cattle as a consequence of selection for growth rate in a stressful environment. *Journal* *of Agricultural Science* **96**, 23–38. doi:10.1017/S0021859600031841.

Frisch JE (2000) Using genetics to control cattle parasites: the Rockhampton experience. *International Journal for Parasitology* **30**, 253–264. doi:10.1016/S0020-7519(00)00010-2.

Frisch JE, O'Neill CJ (1998) Comparative evaluation of beef cattle breeds of African, European and Indian origins. 2. Resistance to cattle ticks and gastrointestinal nematodes. *Animal Science* **67**, 39–48. doi:10.1017/S1357729800009772.

Frisch JE, Vercoe JE (1984) An analysis of growth of different cattle genotypes reared in different environments. *Journal of Agricultural Science* **103**, 137–153. doi:10.1017/S0021859600043409.

Gillard P, Monypenny R (1990) A decision support model to evaluate the effects of drought and stocking rate on beef cattle properties in northern Australia. *Agricultural Systems* **34**, 37–52. doi:10.1016/0308-521X(90)90092-5.

Gleeson T, Martin P, Mifsud C (2012) Northern Australian beef industry: assessment of risks and opportunities. Report to client prepared for the Northern Australian Ministerial Forum. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Gramshaw D, Walker B (1988) Sown pasture development in Queensland. *Queensland Agricultural Journal* **114**, 93–102.

Ha A, Chapman L (2000) Productivity growth trends across Australian broadacre industries. *Australian Commodities* **7**, 334–340.

Hasker PJS (2000) *Beef Cattle Performance in Northern Australia: A Summary of Recent Research*. Queensland Department of Primary Industries, Brisbane.

Holmes W (1997) Making the change from bullocks. In *Marketing Cattle to South East Asia*. (Eds R Kaus, J Lapworth and R Dunn) pp. 17–25. Queensland Department of Primary Industries, Brisbane.

Holmes WE, Sullivan MT (1994) The live export cattle trade longer-term implications for the north Queensland cattle industry. *Proceedings of Australian Rangeland Society* **8**, 18–21.

Holroyd RG, Fordyce G (2001) Cost-effective strategies from improved fertility in extensive and semi-extensive management conditions in northern Australia. *Proceedings of the International Symposium on Animal Reproduction* (Cordoba, Argentina) **4**, 39–60.

Holroyd RG, O'Rourke PJ (1989) *Collation of Basic Biological Data on Beef Cattle Production in North Australia*. Australian Meat and Livestock Research and Development Corporation.

Howden SM, Reyenga PJ (1999) Methane emissions from Australian livestock: implications of the Kyoto Protocol. *Australian Journal of Agricultural Research* **50**, 1285–1292. doi:10.1071/AR99002.

Hughes L (2003) Climate change and Australia: trends, projections and impacts. *Austral Ecology* **28**, 423–443. doi:10.1046/j.1442-9993.2003.01300.x.

Hunter RA (2012) High-molasses diets for intensive feeding of cattle. *Animal Production Science*. <http://www.publish.csiro.au/?act=view_file&file_id=AN11178.pdf>.

Jayawardhana GA, McCool CJ, Zuill DW, Olm TC (1992) The effect of stocking rate on breeder productivity in the Victoria River District. In *Proceedings of the North West Australia Pastoral Conference*. Northern Territory Department of Primary Industries and Fisheries, Katherine.

Johnston DJ, Barwick SA, Holroyd RG, Fordyce G, Burrow HM (2006) Genetics of female reproduction traits. In *Proceedings of Australian Beef – The Leader! Conference,* March 2006, pp. 47–52. Beef CRC, Armidale.

Johnston DJ, Barwick SA, Corbet NJ, Fordyce G, Holroyd RG, Williams PJ, Burrow HM (2009) Genetics of heifer puberty in two tropical beef genotypes in northern Australia and associations with heifer and steer production traits. *Animal Production Science* **49**, 399–412. doi:10.1071/EA08276.

Johnston DJ, Barwick SA, Fordyce G, Holroyd RG (2010) Understanding the genetics of lactation anoestrus in Brahman beef cattle to enhance genetic evaluation of female reproductive traits. In *Proceedings of the 9th World Congress on Genetics Applied to Animal Production*. CD-Rom Communication No. 0923.

Jones RJ, Sandland RL (1974) The relation between animal gain and stocking rate. Derivation of the relation from the results of grazing trials. *Journal of Agricultural Science* **83**, 335–342. doi:10.1017/S0021859600052035.

Knopke P, Strappazzon L, Mullen J (1995) Productivity growth: total factor productivity on Australian broadacre farms. *Australian Commodities* **2**, 486–497.

Lehane R (1996) *Beating the Odds in a Big Country: The Eradication of Bovine Brucellosis and Tuberculosis in Australia*. CSIRO Publishing, Melbourne.

Lonsdale WM (1994) Inviting trouble: introduced pasture species in northern Australia. *Australian Journal of Ecology* **19**, 345–354. doi:10.1111/j.1442-9993.1994.tb00498.x.

Mariasegaram M, Harrison BE, Bolton JA, Tier B, Henshall JM, Barendse W, Prayaga KC (2012) Fine-mapping the poll locus in Brahman cattle yields the diagnostic marker CSAFG29. *Animal Genetics*10.1111/j.1365-2052.2012.02336.x.

McCosker T, McLean D, Holmes P (2010) Northern beef situation analysis 2009. Meat and Livestock Australia Final Report. <http://www.mla.com.au/Research-and-development/Final-report-details?projectid=14980>.

McDonald L (1988) *Cattle Country: The Beef Cattle Industry in Central Queensland 1850s–1980s*. Booralong Publications, Brisbane.

McRae T (2012) *Australian Cattle Industry Projections 2012*. Meat and Livestock Australia. <http://www.mla.com.au/Prices-and-markets/Trends-and-analysis/Beef/Forecasts/MLA-Australian-cattle-industry-projections-2012>.

Mott JJ, Williams J, Andrew MK, Gillison AN (1985) Australian savanna ecosystems. In *Ecology and Management of the World's Savannas*. (Eds JC Tothill and JJ Mott) pp. 56–82. Australian Academy of Science, Canberra.

Nossal K, Yu S (2010) Productivity growth: trends, drivers and opportunities for broadacre and dairy industries. *Australian Commodities* **17**, 216–230.

O'Rourke PK, Doogan VJ, McCosker TH, Eggington AR (1991a) Prediction of conception rate in extensive beef herds in north-western Australia. 1. Seasonal mating and improved management. *Australian Journal of Experimental Agriculture* **31**, 1–7. doi:10.1071/EA9910001.

O'Rourke PK, Doogan VJ, Robertson DJ, Cooke D (1991b) Prediction of conception rate in extensive beef herds in north-western Australia. 2. Continuous mating and minimal management. *Australian Journal of Experimental Agriculture* **31**, 9–14. doi:10.1071/EA9910009.

O'Rourke PK, Winks L, Kelly AM (1992) *North Australia Beef Producer Survey 1990.* Queensland Department of Primary Industries, Brisbane.

Petherick JC (2005) Animal welfare issues associated with extensive livestock production: the northern Australian beef cattle industry. *Applied Animal Behaviour Science* **92**, 211–234. doi:10.1016/j.applanim.2005.05.009.

PMSEIC (2010) Australia and food security in a changing world: can we feed ourselves and help feed the world in future? Report of the PMSEIC Expert Working Group, October. Prime Minister's Science, Engineering and Innovation Council, Canberra.

Price Waterhouse (2006) Report of findings from a review of the operation of the National Livestock Identification System. Department of Agriculture, Fisheries and Forestry, Canberra. <http://www.daff.gov.au/__data/assets/pdf_file/0019/117325/nlis-report.pdf>.

Robbins GB, Bushell JJ, Butler KL (1987) Decline in plant and animal production from ageing pastures of green panic (*Panicum maximum* var. *trichoglume*). *Journal of Agricultural Science* **108**, 407–417. doi:10.1017/S0021859600079442.

Rudder TH, Seifert GW, Burrow HM (1985) Environmental and genotype effects on fertility in a commercial beef herd in Central Queensland. *Australian Journal of Experimental Agriculture* **25**, 489–496. doi:10.1071/EA9850489.

Shelton M, Dalzell S (2007) Production, economic and environmental benefits of leucaena pastures. *Tropical Grasslands* **41**, 174–190.

Taylor WJ, Rudder TH (1986) Reduction of age at sale for export carcasses: will it affect beef producers in tropical regions? *Proceedings of Australian Society of Animal Production* **16**, 379–382.

Thompson T, Martin P (2011) *Australian Beef: Financial Performance of Beef Cattle Producing Farms 2008–09 to 2010–11.* Australian Bureau of Agricultural and Resource Economics and Sciences. <http://adl.brs.gov.au/data/warehouse/pe_abares99010605/AustBeef_2011_HR_3.0.1.pdf>.

Thompson JM, Polkinghorne R, Anderson CA, Webb LE (2008) Meat Standards Australia. *Australian Journal of Experimental Agriculture (special edn)* **48 (11)**, 129 pp.

Turner HG (1982) Genetic variation of rectal temperature in cows and its relationship to fertility. *Animal Production* **35**, 401–412. doi:10.1017/S0003356100001094.

Turner HG (1984) Variation in rectal temperature in a tropical environment and its relation to growth rate. *Animal Production* **38**, 417–427. doi:10.1017/S0003356100041611.

Turner HG, Short AJ (1972) Effects of field infestations of gastrointestinal helminths and of the cattle tick (*Boophilus microplus*) on growth of three breeds of cattle. *Australian Journal of Agricultural Research* **23**, 177–193. doi:10.1071/AR9720177.

Walker B (1991) Sustaining tropical pastures: summative address. *Tropical Grasslands* **25**, 219–223.

Whan I, Bortolussi G, Backus R (2006) The impact of innovation on beef production in far northern Australia. *Australian Journal of Experimental Agriculture* **46**, 271–282. doi:10.1071/EA05175.

White N, Sutherst RW, Hall N, Whish-Wilson P (2003) The vulnerability of the Australian beef industry to impacts of the cattle tick (*Boophilus microplus*) under climate change. *Climatic Change* **61**, 157–190. doi:10.1023/A:1026354712890.

Winks L (1984) Cattle growth in the dry tropics of Australia. *Australian Meat Research Committee Reviews* **45**, 1–43.

This page intentionally left blank

10 The southern Australian beef industry

M.A. Campbell, B.J. King and M.B. Allworth

A BRIEF HISTORY OF THE SOUTHERN BEEF INDUSTRY

The production of beef in Australia began in southern Australia with the coming of white settlers to Sydney Cove. The first cattle to arrive in 1788 were two bulls and five cows (Historical Records of Australian 1914, cited in Peel 1986). Governor Phillip was given specific orders to conserve and breed livestock to feed an ever-growing community of convicts and marines. Four months later, the cattle strayed from their herdsman and were not found again until November 1795 at a place on the Nepean River near Camden, New South Wales, now known as Cowpastures.

Through the 1790s several mixed lots of cattle were imported into Sydney. Many of them were *Bos indicus* types and originated from the Cape of Good Hope in southern Africa, Calcutta in India or the west coast of America. The high death toll of cattle on the long voyage to Sydney was considered a tragic loss to the developing colony, but it meant that only strong, healthy animals arrived.

In the 1820s expansion took place out of the county of Cumberland and a steady build-up of cattle numbers began. By 1850, Australia had nearly 2 million cattle, with NSW holding the highest number of cattle until 1880 (ABS 1908); numbers increased to 8.6 million by the 1900s. The Australian beef export industry started in the first decade of the 20th century with frozen beef going to South Africa (Cape Colony and Natal), the UK and the Philippines (ABS 2000). The Great Drought of 1895–1903 drastically affected beef production in southern Australian and the volume of beef exports decreased.

The government intervened in 1922 by establishing a meat export bounty on all exported frozen and live beef (*Meat Export Bounties Act* 1922). This supported producers and stopped the closure of several abattoirs across Australia.

Worldwide demand for beef saw cattle prices increase by 40% between 1969 and 1974 (ABS 2000). Costs of production and returns were relatively stable and low wool prices in southern Australia encouraged traditional wool growers to diversify into beef (Bailey and Durand 1986). The Australian cattle industry grew drastically in the 1960–70s and became a booming industry with a herd number totally 29.8 million by 1976 (ABS 2005).

'The decade of the 1970s will long be remembered by all associated with the (Australian) beef industry as one which epitomised the extent to which market forces can change' (Reeves 1982). In 1974, the US, Japanese and European markets contracted and, because of world overproduction, beef prices collapsed, reaching a low in 1975. During this recession, the government investigated several stability schemes, but only Western Australia implemented a 'floor price' for beef (Bailey and Durand 1986).

Recovery came in 1978 with the adoption of cost- and labour-saving practices and restricted consumption, maintenance and investment by producers (Makeham *et al.* 1979). Most importantly, prices recovered with renegotiation of US quotas and other markets, particularly Japan. The new markets of Korea, eastern Europe and the USSR also improved (ABS 2000).

During the 1990s, while growth in the north of Australia was driven by the live export trade (Chapter 9), there was little expansion in the southern beef industry (ABARE 2004). The removal of the Japanese beef import quotas in the early 1990s (Chapter 8) did provide a major driving force for feedlot industry expansion. Consequently there has been a shift in the structure of the southern beef industry away from the production of grass-fed steers and bullocks towards the production of store cattle to be lot-fed, principally on grain-based diets.

Drought influenced the southern beef industry significantly through the 2000s (Hooper 2010). Drought in 2002–03 and 2005–06 resulted in destocking and cattle turnoff rates for slaughter increased, with a concurrent decrease in sale price. In late 2009, seasonal conditions improved and, with the continuing good conditions in 2010–12, southern Australia is poised for sustained herd rebuilding. Indeed, in 2011 the national herd reached its highest level for the last 30 years – 28.8 million (McRae 2012).

STRUCTURE OF THE SOUTHERN BEEF INDUSTRY

General structure

'Southern' Australia is defined by the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) to include southern Western Australia (part of), South Australia, New South Wales, Victoria and Tasmania (Fig. 10.1; Thompson and Martin 2011). In 2011 southern Australia had 17 021 beef producers or 68% of all beef properties in Australia (with more than 100 head) but the southern states carried only 40% of the cattle population (MLA 2011). There are some fundamental differences in industry structure between beef production in southern and northern Australia. In general, these differences involve the:

- scale of enterprise (large-scale in northern Australia);
- number of specialist beef producers (more mixed enterprises in southern Australia);
- intensity of production (more intense production systems in southern Australia).

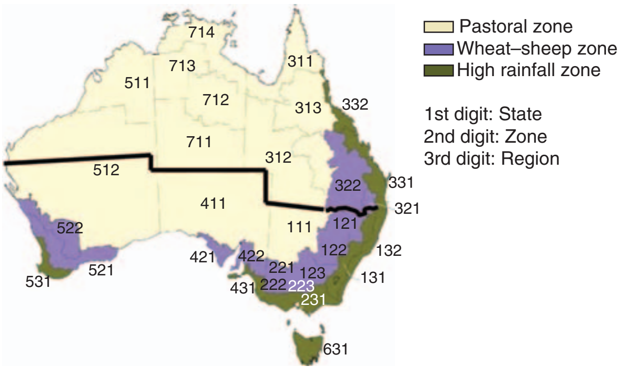


Figure 10.1: Southern Australia (below the states' line) and the Australian broadacre zones and regions as defined by ABARES for use in agricultural survey. Source: ABARES (2012).

ABARES survey data indicate that the average southern beef producer operates a much smaller property (5486 ha, compared to 22 221 ha for northern producers). Along with the smaller property size in the south there are smaller herd sizes, with 61% of cattle in southern parts held on properties that run herds of <800 head (Table 10.1). In contrast, small herds in northern Australia make up only a small percentage of the cattle population (14%). A herd of 600–800 head is considered a large herd in the south.

Generally, the smaller scale of southern beef production is a consequence of enterprises often being run more intensively within a mix of other on-farm enterprises (Nossal *et al.* 2008). Around 64% of southern beef producers receive more than 50% of income from beef cattle (specialised beef producers), compared to 88% of northern beef producers (ABARES 2012).

A longer pasture growing season and more fertile soil is a key feature of many areas of the southern Australian environment, in contrast to the short growing season and lower soil fertility of the northern beef areas. This allows for the intensive grazing of sheep, dairy and beef cattle, as well as grain enterprises (Bailey and Durand 1986). Therefore, southern producers are not only faced with decisions regarding stocking rates, stock movements and sale, but also with more complex decisions about changing the type of livestock grazed or alternate enterprises such as cropping (Sturgess and Malcom 1986). Consequently, price changes and differences between enterprise profitability can mean beef production is one of several on-farm enterprises and not the primary source of income (Kennedy *et al.* 2006; McEachern *et al.* 2012). Moreover, southern beef producers generally deal with better soils, less extreme temperature regimes and more reliable soil moisture (Sturgess and Malcom 1986). The result is a more intensive production environment with improved pasture and fodder conservation allowing higher stocking rates and faster cattle weight gains than is generally found in northern Australia.

Beef production enterprises occur in every region of southern Australia. However, there is considerable variation in southern environments, which significantly

Table 10.1: Distribution of broadacre beef cattle farms in southern Australia (averaged over 2005–06 to 2009–10)

Herd size (head)	No. of farms	% of farms	% of cattle	% value of sales	Average area (ha) operated[1]	Average no. cows mated[1](calves branded)
<100	4956	31.3	5	7		
100–200 (small)	6845	24.3	11	11	1309	63 (54)
200–400 (medium)	3593	22.7	20	21	2296	121 (107)
400–800 (large)	2247	14.2	25	23	7652	261 (233)
800–5400+ (very large)	1192	7.6	38	37	32 638	764 (599)

[1] As at June 2009–10.

Source: Adapted from Thompson and Martin (2011).

impacts on the type of beef production undertaken. Thus, the characteristics of beef production in southern Australia cannot be evaluated accurately at the state level. ABARES defines broadacre zones and regions for the purpose of agricultural statistical survey, which cover all of Australia (ABARES 2012). These zones (Fig. 10.1) consist of combinations of ABARES-defined regions and are differentiated using average annual rainfall:

- 500–1000 mm in the high-rainfall zone;
- 400–700 mm for the temperate (or wheat-sheep) zone;
- 150–400 mm for the pastoral zone (Newton Turner *et al.* 1986).

These differences allow distinction between patterns of pasture growth and opportunities for other enterprises. The southern pastoral zone has been described as being dominated by sheep (compared to beef in the north of the zone). In the high-rainfall zone there is a focus on the beef–sheep and dairying sectors (Davidson 1982). The following discussions will be based on these zones within the southern region defined by Thompson and Martin (2011), using data drawn from the ABARES database.

Within the zones there is considerable variation in the type and scale of production, as well as the type of labour and infrastructure available (Table 10.2).

High-rainfall zone

The majority (68%) of specialised beef producers resided in the high-rainfall zone of southern Australia in 2011, with 31% located in the temperate zone and 1% located in the pastoral zone (ABARES 2012). These specialised beef producers in the high-rainfall zone run cattle herds

Table 10.2: Physical characteristics of specialist (and mixed enterprise) beef producers within the broadacre zones of southern Australian, 30 June 2011

	High rainfall	Southern wheat–sheep	Southern pastoral	All southern Australia
Specialist beef farms (no.)	7417 (2343)	3458 (3245)	135 (424)	11009 (6012)
Cattle on hand (average no. of head)	492 (420)	363 (368)	5371 (382)	435 (399)
Area operated (ha)	704 (1638)	750 (3166)	63 447 (68 926)	4483 (7296)
Cows mated (average no. of head)	212 (193)	162 (157)	2142 (157)	191 (173)
Bulls (average no. of head)	9 (10)	8 (7)	87 (5)	9 (7)
Average age owner (years)	60 (57)	59 (57)	40 (61)	59 (57)
Family labour % of total labour[1]	86 (71)	93 (80)	20 (78)	86 (75)
Cattle sale method (%)				
Auction $/hd	34 (35)	45 (56)	81 (98)	36 (46)
Auction ¢/kg	17 (31)	28 (15)	0 (0)	21 (24)
OTH[2]	25 (19)	12 (9)	0 (1)	16 (13)
Paddock	24 (14)	11 (20)	16 (0)	20 (16)
Other	6 (2)	4 (0)	3 (0.9)	6 (0.1)

[1] % family labour = family labour (weeks)/total labour (weeks).

[2] OTH = over the hook.

Source: ABARES (2012).

averaging 450 head, of which cows make up around 43%. On average, the area of enterprise is 704 ha, and family labour is the main labour source.

Temperate zone

The temperate (wheat–sheep) zone has similar characteristics to the high-rainfall zone, with slightly smaller herds run on larger properties and a heavy reliance on family labour.

Pastoral zone

In contrast to the other zones, the southern pastoral zone holds few specialist beef producers but has the largest scale. The South Australian and the Western Australian (WA) pastoral zones have a major influence on the data for this zone, as herds and property sizes are far bigger than those of the NSW pastoral areas. Much of the required labour is sourced from contractors or employees (ABARES 2012). There were no recorded specialist beef producers in the far west region of NSW.

Transport and infrastructure

Generally, in southern Australia, transport and market infrastructures are well developed. This allows flexibility in production and marketing strategies (Kennedy *et al.* 2006). Infrastructure such as saleyards and abattoirs in the temperate and high-rainfall zones of southern Australia are easily accessible and at convenient distances compared to the lower density of facilities in the southern pastoral zone. Saleyards tend to be located at most major regional centres. It is not uncommon for store and finished cattle to be transported to feedlots and abattoirs in southern Queensland and even commercial bulls to be sold into the Northern Territory from NSW.

Marketing systems

Since the late 1980s the auction selling system has dominated in southern Australia. In 2009–10, just over 60% of cattle were sold by this method (Thompson and Martin 2011). Notable differences exist between the zones in how specialist beef producers sell their cattle (Table 10.2). In 2011, 34% of cattle were sold by auction on a price ($) per head basis with another 17% sold on a price (¢) per kg basis in the high-rainfall zone (ABARES 2012). These methods also dominate in the temperate and pastoral zones, particularly the $/head basis: 45% and 81% of cattle respectively were sold by this method in the year before June 2011. Producers in the high-rainfall zone have the highest use of the ‘over-the-hook’ (OTH) selling method, with 25% of cattle going directly to the abattoir for slaughter. In contrast, almost none of the ABARES-surveyed specialist or mixed-enterprise beef producers in the pastoral zone sold via this method in 2010–11.

Feedlots and processing plants

Feedlots are most commonly located in close proximity to cattle and grain supplies (Chapter 11). In southern Australia these areas include the northern tablelands of NSW, the Riverina area of NSW, Victoria, south-eastern South Australia and southern WA. The 2012 Australian Lot Feeders Association industry survey (ALFA 2012) indicated that the southern states accounted for 51% of the national feedlot capacity (1 266 710 head) and 45% of the 788 625 head of cattle on feed with most feedlots situated in NSW (and southern Queensland). It is increasingly common for major corporate companies such as Teys/Cargill and JBS Australia to own both feedlots and abattoirs.

The intensive production of chilled and frozen beef production in southern Australia relies on the presence of abattoirs and processing plants. In 2012, the number of AUS-MEAT(Chapter 2) accredited abattoirs and boning rooms processing beef in the southern states (including southern WA) was 46 (of which 35 had export markets) and 20 (12 export) respectively (AUS-MEAT 2012). Victoria has the highest number of processing plants. In WA plants are concentrated in the coastal and temperate regions of the state.

Summary

Overall, the structure of the southern Australian beef industry is different from that of the north due to the environmental and infrastructural conditions under which producers operate. Temperate and high-rainfall zone enterprises are typically smaller and more intensively run, often within a mix of other enterprises. Transport and market infrastructures in these zones are well developed. This allows flexibility in production and marketing strategies and producers are more likely to choose a value-based marketing method such as over-the-hook sale to allow feedback-based decision-making. The pastoral zone (arid zone) enterprises are an exception where shorter pasture growing seasons prevail and the scale of enterprise increases. This is particularly true for the arid zones of South Australia and WA where producers specialise solely in cattle production. Cattle in pastoral zone areas are almost all sold via the $/head auction or by paddock sales in store condition to feedlots or at weaner sales.

BREEDS USED IN SOUTHERN BEEF ENTERPRISES

Southern Australian beef enterprises have traditionally been characterised by the use of British breeds, such as Angus and Herefords, for weaner production. European breeds such as Charolais and Limousin have been used more widely since the 1980s for their extra muscle and growth. The use of crossbreeding (Chapter 17) for hybrid vigour and the development of true composite breeds have become more common. The southern Australian beef industry requires cattle breeds that produce young, well-grown cattle with high-quality carcass characteristics (Chapter 2). There is a market resistance to high content Bos *indicus* cattle due to perceived suitability for the temperate environment and specific market specifications, so they are not commonly used in southern Australia except in environments where their heat tolerance and tick resistance traits can be beneficial (e.g. the north coast of NSW).

Hereford cattle have traditionally been the breed of choice in southern Australia because of their perceived versatility in a variety of markets and environments. They have the ability to produce heavy, high-quality carcasses and suit both grass and grain finishing. The demand for Angus cattle increased during the late 1990s because of their superior marbling ability (McKiernan *et al*. 2009) and, with the infusion of US genetics, they are now larger-framed and later-maturing than the traditional breed type. This makes them very suited to the high-quality Japanese and Korean markets from both the feedlot and grass-fed sectors and has given them a strong reputation in the market. Their black hide attractiveness gives an average price premium of 5–10¢/kg (3–5%) over other breeds in the saleyard (Exton 2012) and a 10c/kg premium in feedlots. However, when producers choose to sell over-the-hooks, through a value-based market, objective measures of traits such as carcass weight, meat colour and fat depth makes breed less important (Chapter 3). Angus cattle are now the dominant choice for southern Australia with Herefords (both Polled and Horned), Shorthorns, Limousin, Charolais and Murray Greys also used extensively (Allen 2002).

Table 10.3: Number of bulls born in 2012 in southern Australia and registered on Breedplan, by breed

Breed	No. of bulls born in 2012 and registered on Breedplan in southern Australia
Angus	28 385
Hereford	5462
Charolais	3038
Limousin	2040
Murray Grey	1694
Shorthorn	1349
Simmental	1176
Wagyu	95

Source: C Tesling, *pers. comm.* (2013); and Breedplan (2013).

The main European breeds that are popular in southern Australia are Charolais, Simmental and Limousin. The European breeds are useful for their high growth and hence heavy weight for age but they have a high maintenance energy requirement on average because of their larger body size (Jenkins and Ferrell 1985). European breeds are often used as a terminal sire to take advantage of the benefit of direct heterosis on growth but it is important that adequate nutrition is provided (Hearnshaw *et al*. 1995).

Wagyu cattle were first imported in the early 1990s and have grown in popularity in recent years. They are specifically bred for their high marbling and late-maturing pattern to suit the long-fed, high-quality Japanese market (Chapter 8), though some are sold domestically as a high-value gourmet product. The number of pure bred Wagyu cattle is low (relative to other breeds) in southern Australia and crossbreeding programs using Wagyu bulls over an Angus dam to produce a first-cross (F1) animal have been used to accelerate the dissemination of Wagyu genes.

The Regional Combinations project in southern Australia studied how animals with differing genetic potential for fatness and yield respond to changes in nutrition, and hence their production, carcass and meat quality traits (McKiernan *et al*. 2009). Sires were chosen to represent genetic diversity between high retail beef yield (RBY%) and high intramuscular fat (IMF%). The high RBY% sires were drawn from the Limousin, Charolais and Angus breeds and the high IMF% sires were drawn from the Angus, Red Wagyu (Japanese Brown) and Black Wagyu breeds. A third group was formed by selecting animals from the Angus and Red Wagyu breeds for both high IMF% and high RBY% (McKiernan *et al*. 2005). The cows were drawn from a self-replacing Hereford herd and, in total, 43 sires were used across 500–800 cows at each mating. This resulted in over 1200 progeny across all the treatments, with a minimum of 108 calves in a treatment group. Progeny were then grown on different nutritional regimes, resulting in either high or low growth from weaning until feedlot entry. Some key findings included:

- European types have a clear advantage in terms of hot standard carcass weight, eye muscle area and RBY%;
- Angus and Wagyu showed superior marbling to the European cattle, however, there was little difference between the Angus and Wagyu. This may have been a result of the short 100-day grain finishing program and does not predict outcomes for longer feeding situations (McKiernan *et al*. 2009).

While some southern commercial cattle breeders still maintain relatively purebred herds, there has been an increasing trend towards the use of crossbreeding in commercial herds although robust figures on this are hard to collate. Increases in profitability from crossbreeding occur through improved fertility and suitability to a particular environment or market due to expression of both maternal and direct heterosis (Gosey 2005; Chapter 17).

A common crossbreeding scenario in southern Australia is the production of the F1 Black Baldy female (Fig. 10.2) achieved by crossing an Angus bull over Hereford cows to produce heifers which express a maternal heterosis for lowly heritable traits such as fertility (Cammack *et al*. 2009). Heterosis can also come in the form of increased growth, so these females reach target mating weights faster. A terminal sire from a European breed or another British breed is usually used to mate with F1 cows to produce calves with superior muscling and growth and therefore heavier carcass weight for age to that of the straight British breeds (direct heterosis).

The use of composite cattle is becoming more common in southern Australian beef enterprises, with several studs now offering crossbred or full composite bulls. Composite cattle have been bred through crossing several breeds then stabilising the genetic base over several generations. Crossbred bulls are not genetically stabilised and therefore will have more variation in their progeny. Composite cattle have advantage in terms of heterosis for growth, carcass weight and fertility without the more complex management of a crossbreeding program (Gosey 2005; Chapter 17).

Work at the Meat Animal Research Centre, USA (Gosey 2005) has laid the basis for much of the composite breeding carried out in southern Australia, based on the similarity between the markets. The most profitable combination of breeds for the US market was a four-breed composite that included Angus, Hereford, Simmental and Gelbvieh genetics. Many of the composite bulls now sold in southern Australia likewise include a mix of British and European genetics and they have been successful in making the use of European genetics more appealing to traditional British cattle breeders. Composite bulls are sold under many different names and some have been trademarked, e.g. Stabilizer, SimAngus, Australian Beef Composite and Limflex.

Figure 10.2: A Black Baldy.

There are also composites which contain *Bos indicus* breeds that are very useful in southern environments, especially those in the drier inland regions that are exposed to weather extremes in summer. In these areas, the use of Santa Gertrudis or Santa Gertrudis *x* Angus female to produce offspring with good heat tolerance is quite common. Breeders in parts of southern Australia that experience subtropical conditions such as the north coast of NSW also use *Bos indicus* cross cattle. The crossbred progeny have higher growth rates than purebred Hereford cattle in these subtropical and tropical environments (Arthur *et al*. 1994; Barlow and O'Neill 1978) where feed quality can be low and exposure to external parasites high (Chapter 13). There is greater market acceptance of *Bos indicus* cattle in regions of northern NSW and central Australia, being closer to the northern Australian cattle industry.

MARKETS AND MARKET SPECIFICATIONS

The production of beef cattle in southern Australia is targeted at supplying young grass-fed and grain-fed beef for the domestic and export markets, with a high focus on the higher quality (marbling) grain-fed carcasses for the north Asian export market that require a long grain-feeding program. Cattle can be channelled into these markets via several marketing options (Chapter 3).

Selling options

Selling cattle at auction through a saleyard is the traditional and most common channel of marketing for all types of cattle from a southern farm, with 3.5 million cattle (60%) traded through yards each year (Kennedy *et al*. 2006). With the high concentration of feedlots and beef processing plants in southern Australia, producers have a greater opportunity to sell directly to them. This facilitates feedback on the cattle sold and enables the cattle manager to make informed management decisions for future cattle consignments. The internet-based system AuctionsPlus Pty Ltd is another alternative: it operates online auctions and is increasing in popularity with over 250 000 (~7% of the number of cattle being sold through saleyards) cattle sold using this channel during the financial year ending 2012 (Chapter 3).

Applied marketing decisions

A major difference between beef production in southern and northern Australia is that in southern Australia producers have the ability to sell cattle at all times of the year from weaning through to finished heavy cattle; they are not restricted by a wet season or major mustering operations. As a result, they continually assess pasture and the potential for cattle to grow to target weights for the available range of markets.

The first opportunity for breeding enterprises to sell cattle is at weaning, which is typically early in the calendar year. A highlight of the southern Australian sale year is the annual weaner auction sales held from January to May. These attract buyers looking to background cattle for the feedlot market or to grow weaners on pasture to a slaughter weight. Normally the highest prices paid in the weaner sales are for cattle that are vendor-bred, weaned before sale and well grown for their age. Weaner sales that are early in the year attract heavy weaners that were born the previous autumn, along with lighter weaners born in the spring.

As the year progresses, producers regularly assess the prevailing season and pasture growth to determine the potential for growing cattle out to heavier weights. The next marketing opportunity after weaning is to sell store cattle direct to feedlots at weights ranging from 350–500 kg or, as store cattle through the saleyards, using online auctions or a private agent. The latter are often bought by other producers that will let them gain more weight on grass to reach a feedlot entry weight or be finished for slaughter. Some feedlots require that cattle have whole-of-life traceability to fulfil requirements of some markets (e.g. EU, Japan). Grain-finishing steers and heifers in feedlots is common in southern Australia. Feedlots have adopted market descriptions for their cattle based on the number of days of a feeding program. There are short (60–90 days), medium (90–180 days) and long (180 days +) grain-feeding programs and each targets a variety of markets (Chapter 11). The short-fed market mainly targets local supermarket trade, some restaurant and food service outlets. The medium-fed market is generally for the higher-value domestic and export markets such as Korea. The long-fed market is mainly to Japan, which requires carcasses to have a high level of marbling. It is usually restricted to Angus or Wagyu cattle or a first cross (F1) of those breeds.

The final option for producers selling young cattle, is to finish cattle on grass for slaughter. Producers typically aim for cattle to reach 240–320 kg carcass weight with a fat cover of 5–15 mm to allow their cattle to fit within several of the processor's specification grids (Table 10.4; Chapter 3). These cattle can be sold through the 'fat sales' at a saleyard, at online auctions or direct to abattoirs. Those sold direct to abattoirs are sold over-the-hooks to meet the specifications set by the individual abattoir.

Cattle breeders in southern Australia have a proportion (20–30%) of sale stock income from cull cows depending on their herd structure and female replacement policy. Cows are culled based on fertility or age or because they are surplus to requirement. Cull cows are usually sent for slaughter, either direct to the processor or through a saleyard. Their carcasses are broken down into some low-value primal cuts, the majority going into manufacturing beef.

Specifications and processing

Cattle sold directly to abattoirs and feedlots are required to meet the company's specifications for either live animals or carcasses and are paid on a value-based marketing method. A price grid (Table 10.4) will describe the type of cattle the company requires in terms of specified traits and the premium or discount (relative to a ¢/kg carcass weight base price) for variation in traits away from the requirements. Depending on the market, specifications can be basic (e.g. liveweight, dentition, sex, fat depth) or more detailed (e.g. a requirement for product to be graded through Meat Standards Australia – MSA).

There are numerous companies that own both abattoir and feedlot facilities and so a producer might deal with the same company in both instances. For example, a major player is JBS Australia, which owns and operates nine abattoirs processing beef and five beef feedlots across Australia, with five of the processing plants and three of the feedlots located in southern Australia. Modern abattoirs generally have boning rooms attached to them. It is very rare that a whole carcass is sold to a particular market; rather, it is boned into primal cuts (e.g. rump, briskets, strip loins) and sold as boxed beef (Chapter 2). This system of boning on-site reduces freight costs and is used to add value to the carcass. Some of the larger abattoirs with complete boning facilities are owned by Teys Australia, T&R Murray Bridge and JBS Australia.

The EU grain-fed market quota increased to 48 200 t in 2012 from the initial quota of 20 000 t in 2009 (Chapter 4) and therefore feedlot and abattoir capacity have been made available to service this market for southern Australian producers. The EU market has two main requirements:

1. that the animal has lifetime traceability;
2. that no hormone growth promotants (HGPs) be used.

Producers who wish to supply this market need to become accredited under the EU Cattle Accreditation Scheme (EUCAS), as do the feedlots and abattoirs.

Many producers in southern Australia are registered to sell cattle under the MSA meat eating quality guarantee scheme (Chapter 2). Producers can receive price premiums for carcasses that grade to the MSA minimum standard. An example of a price premium is 25¢/kg carcass weight for cattle that grade MSA (Table 10.4).

There some niche markets in southern Australia such as Certified Australian Angus Beef (CAAB), Hereford Prime and Coorong Angus that have specifications

Table 10.4: An example price grid for a beef processor in southern Australia

	Carcass specification grid				
	MSA steer	**Trade steer**	**MSA heifer**	**Trade heifer**	**Cow**
Teeth	0–2	0–2	0–3	0–4	0–8
FAT (mm)	6–22	6–22	6–23	6–24	0–32
	Less 5¢/kg for fat 23–32 mm; less 30¢/kg for fat >32 mm				
Bruising	Nil	Nil	Nil	Nil	Nil
Butt shape	ABC	ABC	ABC	ABC	ABCDE
Meat colour	1B-3	1A-3	1A-4	1A-5	1A-5
Fat colour[1]	0–3	0–3	0–3	0–3	0–5
Weight (kg)	180–340	180–340	180–340	180–340	160+
Weight	**Price**				
340+	–	–	–	–	280
320–340	350	325	345	320	280
300–320	360	335	355	330	280
280–300	360	335	355	330	275
260–280	360	335	355	330	270
240–260	350	325	345	320	265
220–240	345	320	340	315	260
200–220	335	310	330	305	255
180–200	315	290	310	285	240
160–180	–	–	–	–	145
140–160	–	–	–	–	45
120–140	–	–	–	–	25
100–120	–	–	–	–	5

Refer to Chapter 2.

[1] Fat colour is on a scale of 1–9: 1 = pure white and 9 = dark yellow.

Source: Adapted from available processor grids (spring 2012).

particular to their brand. These specifications are normally outside the typical carcass specifications and can include breed, location and finishing diet (grain or grass) and organic status. They are normally marketed as a gourmet product and producers who supply these niches can receive a premium above standard market rates.

BEEF PRODUCTION IN THE SOUTHERN ENVIRONMENT

Beef production systems in southern Australia

The pasture base of southern Australia includes native and sown improved pastures. The introduction of the more improved species underpins the intensive nature of beef production in many southern Australian high-rainfall and sheep–wheat regions (Fig. 10.1).

Wolfe (2009) described the pastures of southern Australia. In short, original native pastures dominated by warm-season tussock grasses (e.g. kangaroo grass, *Themeda australis*) have been degraded by the introduction of sheep and cattle and have transitioned into grazing-tolerant species like the wallaby grasses (*Rytidosperma* spp.) and redgrass (*Bothriochloa macra*). The broadacre application of superphosphate and the introduction of legumes have improved the quality of native pastures. Native pastures have also been altered by the introduction of seed through animal feeds, such as silver grass (*Vulpia* spp.), barley grass (*Hordeum leporinum*) and capeweed (*Arctotheca calendula*). Dear and Ewing (2008) indicated that there are 32 million ha of unimproved native pastures and 6 million-ha of improved native pastures (fertilised or fertilised + oversown), mainly in southern areas with >550 mm average annual rainfall.

Sown pastures play an important role in southern Australia with up to 25 million ha of sown pastures in southern regions. Important pasture species including perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) are restricted to areas with annual median rainfall of 700 mm or greater in Victoria and ~750 mm along the coast and higher tablelands of NSW and the far south of Queensland. According to Dear and Ewing (2008) there were 6 million ha of pastures containing perennial ryegrass and/or white clover in southern Australia in 1997. There are also smaller areas of phalaris (*Phalaris aquatica*) and cocksfoot (*Dactylis glomerata*) in NSW, Victoria and Tasmania, as well as tall fescue (*Festuca arundinacea*) in NSW. Subterranean clover is an important legume in both improved perennial and native pastures.

Industry advisers and researchers have encouraged the incorporation of perennial species into southern pastures due to their increased yield and quality compared with native species (Chapter 15). Phalaris is reasonably drought-tolerant and is usually sown with subterranean clover; it is limited inland to areas with rainfall >300 mm in WA, 350 mm in South Australia and north-western Victoria, 400 mm in southern NSW and 500 mm in northern NSW. In 1997, there were 4.75 million ha of improved pastures containing phalaris (Dear and Ewing 2008)

Lucerne (*Medicago sativa*) has been advocated as a component of permanent or ley pastures to enhance livestock production, nitrogen fixation and/or water extraction from the soil profile. Lucerne, lucerne/grass and lucerne/annual mixtures are used for grazing and hay production on alluvial soils and aeolian (wind-borne) sediments in southern Australia. Lucerne is adapted to areas above the 500 mm annual rainfall isohyet in northern NSW and the 400 mm isohyet in southern NSW, Victoria, South Australia and WA. Lucerne can fill feed gaps during the late summer and autumn period when improved pasture species such as ryegrass and phalaris are dormant. There were 3.5 million ha of lucerne pastures in 1997 (Dear and Ewing 2008).

Annual legumes, principally subterranean (sub) clover (*Trifolium subterraneum*) and annual medics (*Medicago* spp.), formed the basis for the legume ley pasture system in the Australian wheat belt (where there are ~22 million ha cropped each year plus a further 11 million ha in the pasture phase). Annual legumes persist in areas above the 400 mm isohyet in southern NSW and 350 mm in Victoria, South Australia and WA. There is a wide range of cultivars available of both subclover (used in temperate croplands, slopes and tablelands) and medics (croplands and plains).

Year-round stocking rates typically around 0.5–2 dry sheep equivalents (DSE) per ha (or the equivalent in cattle) are carried on non-degraded native pastures, while 8–10 DSE/ha are carried on improved native and good-quality sown improved pastures (Wolfe 2009). Much higher stocking rates (e.g. 12–25 DSE/ha) are achieved in beef production systems in the higher-rainfall regions on sown improved perennial-based pastures. Increasingly, beef production is based on perennial pastures such as phalaris with subterranean clovers. The pasture-based system allows beef to be produced in most years at a relatively low cost (pasture production being generally at least half the cost of supplementary feeds), but it is dependent on adequate rainfall.

There are three main climatic regions in southern Australia: high-rainfall, temperate and arid. In these regions, beef production competes with and is complemented by dairy (mainly in high-rainfall regions), cropping (predominantly in the temperate regions) and sheep (in all three regions). Beef production in higher-rainfall regions has a greater tendency to finish young cattle (for feedlot and slaughter) on the more productive pasture base, in temperate areas it predominantly produces store cattle and in the arid zones it produces older finished animals. Kennedy *et al*. (2006; Table 10.5) suggested that six production sectors exist in the Australian beef industry:

1. specialised breeding, with sale of calves at weaning (7–10 months, 200–350 kg);
2. breeding and growing, with sale of store yearling cattle;
3 breeding and finishing, with sale of finished yearling (or older) cattle for slaughter;
4. specialised growing and backgrounding;
5. specialised finishing on pastures;
6. specialised finishing in feedlots.

A generally reliable and abundant spring growth of pasture is the basis for beef production in southern Australia. Using the spring flush of pasture and managing the relative pasture deficits in winter and frequently in autumn is an important part of beef production systems.

The beef production system in southern Australia has changed from a traditional cow–calf operation with the sale of vealers to a predominantly cow–calf operation but with steers and heifers retained to grow out to meet feedlot entry requirements while utilising pasture more efficiently. A section of the cattle industry utilises a system of 'trading cattle' where they buy yearling steers and heifers and grow them out to feedlot entry or slaughter weights. This enterprise can be conducted as the sole beef enterprise on a farm or in combination with a breeding operation. It can be a profitable way to increase pasture utilisation without the risk of carrying a high number of breeding cows.

Table 10.5: Prevalence of the beef production sectors in the climatic regions of southern Australia

	High-rainfall	Temperate	Arid
Specialised breeding	+++	+	+
Breeding and growing	++	+++	+
Breeding and finishing	+++	+	++
Specialised growing and backgrounding	+	++	
Specialised finishing on pastures	++	+	
Specialised finishing in feedlots		+	

Note: the number of + shows the relative number of each production system in a region.
Source: Adapted from Kennedy *et al.* (2006).

Key management decisions for beef producers

The key management decisions are:

1. time of calving;
2. stocking rate;
3. breed/crossbreed;
4. market identificatin/selling strategy;
5. whether to purchase or breed replacement heifers.

Time of calving depends on rainfall distribution and marketing strategy, the latter influenced by pasture productivity, breed and producer perception of markets. Typical management activities for a beef enterprise in a temperate and summer-rainfall zone are presented in Tables 10.6 and 10.7.

In the more southern regions, autumn calving has been more common, allowing the spring flush of pasture to be utilised by older calves before sale in summer. The strong feedlot industry and a decrease in premiums for younger fat cattle have resulted in a shift towards a late winter–spring calving.

Table 10.6: Typical management program of major events for beef production in a summer-rainfall environment with a late winter–spring calving

	Operation	Decision
January		
February		Sell yearlings
March		
April	Wean, pregnancy test	Sell NDP[1] cows
May		Sell weaners or keep
June		Feed weaners if pasture supply does not meet requirements
July		Feed cows if pasture supply does not meet requirements
August	Calving	
September	Calving	
October	Calf marking	
November	Joining	
December	Joining	

[1] NDP = not diagnosed pregnant.

Table 10.7: Typical management program of major events for beef production in a temperate environment

	Calving time					
	Autumn		Winter		Late winter–spring	
	Operation	Decision	Operation	Decision	Operation	Decision
January	Weaning, pregnancy test, sell NDP[1] cows	Sell surplus calves as vealers or retain and sell in spring				
February				Weaning, pregnancy test, sell NDP cows	Wean, pregnancy test	Weaning depends on season
March	Calving	Feed cows if pasture supply does not meet requirements		Feed weaners if pasture supply does not meet requirements		Feed weaners if pasture supply does not meet requirements
April						Sell NDP cows or fatten
May	Calf marking					
June	Joining	Feed cows	Calving	Feed cows, weaners if pasture supply does not meet requirements		Feed weaners if pasture supply does not meet requirements
July						
August			Calf marking		Calving	
September			Joining			Sell cows if kept
October					Calf marking	
November		Sell carryover yearlings		Sell surplus weaners	Joining	Sell yearlings
December	Weaning if insufficient pasture	Work out selling options				

[1] NDP = not diagnosed pregnant.

In summer-rainfall regions such as northern NSW, spring calving has long been standard practice as summer-dominant rainfall enables finishing of yearling cattle or sufficient growth of calves for sale before winter. In summer-rainfall areas, calving is usually in late winter–spring. Producers either sell surplus weaner calves in May before the winter, or carry over calves and sell them as stores or finished stock in late summer the following year (Kennedy *et al.* 2006).

A unique production system exists in the Northern Rivers region of NSW where breeding herds produce weaner cattle that generally are sold to other areas such as the Northern Tablelands region, to be grown out. This is due to the slower growth rates of cattle on the coastal pastures compared to the highly improved pasture base of the tablelands region.

In uniform- and winter-dominant rainfall areas, calving patterns are more variable. The market for selling older, heavier store animals to feedlots (typically 380–500 kg liveweight) has favoured a later calving in midwinter or late winter–spring, with a general tendency for later calving in southern areas. Calves are weaned from February through to May, depending on seasonal conditions; earlier if pastures are in short supply and cow body condition is falling. Calves are maintained over winter, sometimes requiring supplementary feed, then grown out to reach target weights using the spring pasture flush.

Supplementary feeding may be necessary in all calving systems, usually in June–July and in poorer seasons from February to May (Fig. 10.3). The class of stock supplemented depends on the timing of calving relative to pasture growth. In the autumn calving system, the cows receive most or all of the supplementary feed. This is a result of the cow calving and lactating during a period of low pasture availability and cold temperatures in June

Figure 10.3: Angus cows being supplementary fed cereal hay near Holbrook in southern NSW. Photo: B. Allworth.

and July. As a result, supplementary feeding to cows is necessary if pasture is insufficient to meet requirements (e.g. lactating on short winter pastures). Later calving systems (e.g. late winter–spring calving) place less pressure on the cow but often require supplementary feeding to the calves following weaning. Hay and silage are the main supplements used, with silage more common since the 1990s. The roughage supplements are typically conserved on-farm in the preceding spring from surplus pasture or crop. Grain is used during drought or prolonged feeding periods, but usually in combination with hay or silage.

Calving time will affect stocking rate. Aligning calving to the late winter–early spring flush of pasture will provide high nutrition at a time when nutritional demands of the cow are high. As a consequence, the lowest nutrient requirement of the cows occurs in winter, when pasture growth is limited. This calving system will run higher year-round stocking rates than an autumn calving system. The South-west Farm Monitor project run by the Victorian Department of Primary Industries showed that a spring calving system can run on average a 20% higher stocking rate than an autumn calving system (DPI Victoria 2009). Autumn calving systems need to join cows in late autumn–winter, times when pasture availability can be low. As a consequence, cow body condition needs to be higher to maintain fertility and this will reduce year-round stocking rates in those systems.

Main cattle husbandry activities

Calf marking usually occurs at two to three months of age. Calves are generally vaccinated (at least against clostridial diseases) and male calves are castrated (in commercial herds) (Chapter 13). Fire-branding to permanently identify animals for a given property has largely ceased, due to both animal welfare and hide damage concerns. Instead, calves receive a National Livestock Identification System (NLIS) tag which provides both property and individual radio-frequency identification. If this is not done at marking, it must be done before the animals leaving the property. Calves may also receive a property ear notch and/or individual management tag.

The timing and management of weaning also varies with the calving system. Vealer production systems generally aim to wean 280–350 kg calves at nine to10 months of age, with surplus calves sold directly off their mothers. In steer production systems, weaning occurs anytime between six and 10 months, usually determined by seasonal conditions and cow condition score. Earlier weaning (e.g. six months) is favoured in poorer seasons and/or when cow condition score drops below predetermined levels, typically a body condition score of 2. Conversely, weaning may be delayed in good seasons when cow condition score is maintained despite lactation.

Yard weaning is a recommended method of weaning and has been widely promoted (Black and Scott 2002). It involves locking the calves in a large holding yard and feeding hay or silage for seven to 10 days. Frequent handling and interaction with the cattle is recommended to settle the cattle down. The combination of feeding and interaction is designed to make cattle more conditioned to entering feedlots (Chapter 21).

PERFORMANCE OF SOUTHERN BEEF ENTERPRISES

Breeding herd performance

Breeding herd performance and weaner throughput have a major impact on enterprise profitability (Black and Scott 2002). Broad estimates of performance indicators for southern Australia are presented in Table 10.8. These values are indicative; they vary within and between breeds and regions.

Cow efficiency is a key factor in a successfully reproducing herd. It is dependent on heifer development to first joining and the cow's ability to maintain body condition at later joining (Walmsley and Parnell 2010; Chapter 14). Breeding strategies to produce cattle with body composition (i.e. fat levels) suitable for a range of markets can also impact on cow fertility, particularly in environments with poor nutritional resources (Pitchford and Graham 2010). The industry requires cows that can store and utilise body

Table 10.8: Indicative productivity indicators (minimum values) in the southern beef industry

Productivity indicator					
Cows		**Bulls**		**Calves**	
Age at first calving (years)	2.5	Mating load (cows per bull)	20	Age at weaning (days)	220
Inter-calving interval (days)	390	Years bull used in herds	2	Daily gain to weaning (kg/day)	1.1
Years cow in herd	5			Age at slaughter (years)	1.7
Average conception – natural (%)	90			Liveweight at slaughter (kg)	400
Average conception – AI (%)	85				

Source: Adapted from Allen (2002).

fat at strategic times (i.e. during years with poor pasture supply) and therefore are more likely to maintain fertility and produce progeny to meet the requirements of high-quality markets. The Beef CRC maternal productivity program aimed to create a balanced approach to selection (Pitchford and Graham 2010). At present, beef industry agencies such as Meat and Livestock Australia (MLA) have developed guidelines (e.g. More Beef from Pastures) to assist producers improve breeding herd performance (Table 10.9; Chapter 18).

Table 10.9: Guidelines for managing British breed beef cattle to achieve high reproduction efficiency

Mating	Heifers	Average post weaning liveweight gain of 0.5 kg/day to reach target weights Joining weight 280 kg, condition score 3 at 15 months or age (minimum)
	First calf cows	Condition score 3.0–3.5
	Cows	Condition score 2.5–3.5
	Bulls	Condition score 2.0–3.0
		Scrotal circumference (minimum) 12–15 months 30 cm 18 months 32 cm 2 + years 34 cm
	Bull:female ratios	Minimum 2:100 or per herd
		Intensive southern herds 2:100 (maximum)
		Extensive/pastoral zone 4:100 (maximum)
	Length of mating	Cows 45–60 days Heifers 45 days
Post conception	Heifers	Liveweight gain of 0.5 kg/day to reach target weights Do not overfeed Pregnancy test
	Cows	Maintain fat score of 2.5–3.5[1] Consider supplementation <2.0 Pregnancy test
	Calves	Wean calves before cow fat score falls to 2.5 Minimum 100 kg or 100 days from when last calf born Pasture conditions maximise intake of at least 11.5 MJ ME/kg DM[2] and 15% crude protein Yard wean
Calving	Heifers	Calve between fat score 2.5–3.0 Supervise and provide timely assistance
	Cows	Calve between fat score 2.5–3.5
	Pastures	Minimum 1500 kg green DM/ha

[1] Cattle fat score is a scale of 1–6: 1 = emaciated and 6 = obese.

[2] MJ ME/kg DM = megajoules of metabolisable energy per kilogram dry matter.

Source: Black and Scott (2002).

Table 10.10: Annual productivity of specialist beef cattle enterprises in the southern broadacre zones and southern Australia and northern Australia averaged for 2007/08 to 2010/11

	High rainfall	Temperate	Pastoral	Southern Australia	Northern Australia
Calf marking rate (%)	87	89	67	86	71
Turnoff rate (%)	45	58	25	47	33
Death rate (%)	1.8	1.3	5.4	2.2	2.5

Calf marking rate = no. of calves marked per 100 cows joined.
Turnoff rate = % of total herd that was sold.
Death rate = % of total herd that died during the year.
Source: ABARES (2012).

Productivity and profitability of beef enterprises

Productivity reflects the ability to produce output given available resources or inputs (Nossal *et al.* 2008; Chapter 18). Typical measures of performance used by ABARES to compare productivity include branding rates, cattle turnoff rates, death rates and total factor productivity. Calf marking rates and cattle turnoff rates are typically higher in southern Australia than in northern Australia, particularly in the high-rainfall and temperate zones of the south (Table 10.10; ABARES 2012). This is a result of the higher rainfall and the greater opportunity to manage herd nutrition more cost-effectively (Thompson and Martin 2011). Over the last two decades, calf marking rates have trended upwards in the south to be on average over 85% due to improved genetics, improved pasture and better herd and health management. They have remained relatively unchanged in northern Australia, at around 70% (Fig. 10.4; Chapter 9). Dry seasonal conditions during the 2005–06 drought were a good example of how a dry season can significantly affect cow fertility, resulting in a decline of calf marking rates in those years. The high death rate of cattle in the pastoral zone has been influenced by high cattle deaths in WA, particularly in 2010–11, due to drought (McRae 2012).

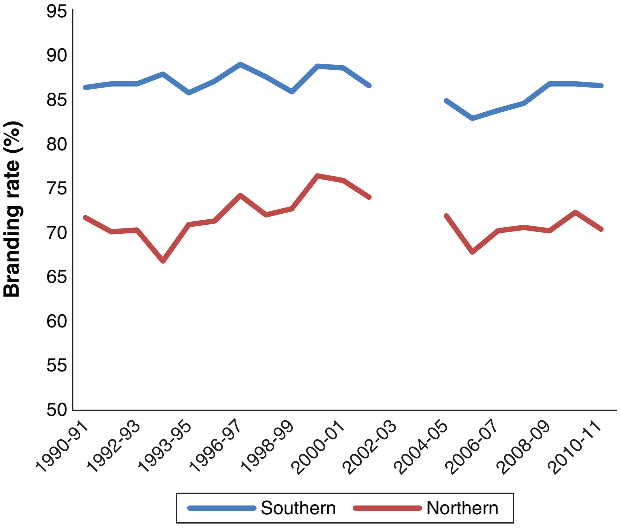


Figure 10.4: Calf marking (branding) rates for beef enterprises in Australia from 1990/91 to 2010/11. Source: ABARES (2012).

Overall, the southern Australia beef industry had year-to-year fluctuations in the Total Farm Productivity (TFP) index (Chapter 18), in part due to significant sensitivity to drought conditions and reduced feed availability. This causes alternating periods of destocking and herd rebuilding, and interruptions to income as producers retain breeding stock. It may also be due to the high proportion of mixed-enterprise producers in southern Australia shifting between beef cattle production and other enterprises such as cropping and sheep production, due to differences in returns from each enterprise. However, the general trend of TFP for beef producers over the last decade has been positive due to a combination of expanding output and contracting input use. Generally better pasture and herd management have increased productivity, with potential for smaller-scale production systems to be profitable (Chapter 18). In contrast, the TFP index trend in northern Australia was flat until 2005–06. It then increased due to young cattle being sold to the live trade and more breeding cows being run on large properties (Nossal *et al.* 2008).

The financial performance including farm cash income, equity level and farm business profit of southern beef producers with over 100 cows has been reported by ABARES (Thompson and Martin 2011). In the two years to 2009–10, the average farm cash income was around AUD$60 000. In 2010–11, for all types of beef farms with over 100 cows in southern Australia, the average farm business profit was $43 654 with producer equity of 90% (ABARES 2012; Chapter 20).

Farm income is dependent on seasonal conditions. In good seasons, although receipts from beef cattle sales will fall due to herd rebuilding and a reduced number of cattle sold, the expected farm expenditure on fodder will be less and purchase of stock will be small due to limited supply

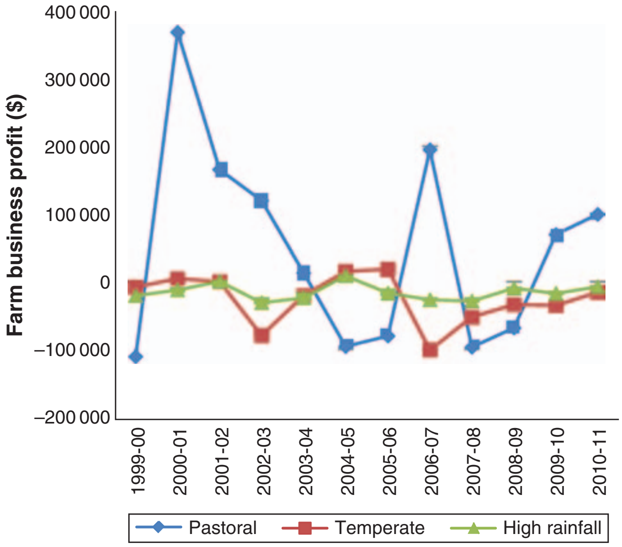


Figure 10.5: Farm business profit by zone for specialist producers, 1999/00 to 2010/11. Source: ABARES (2012).

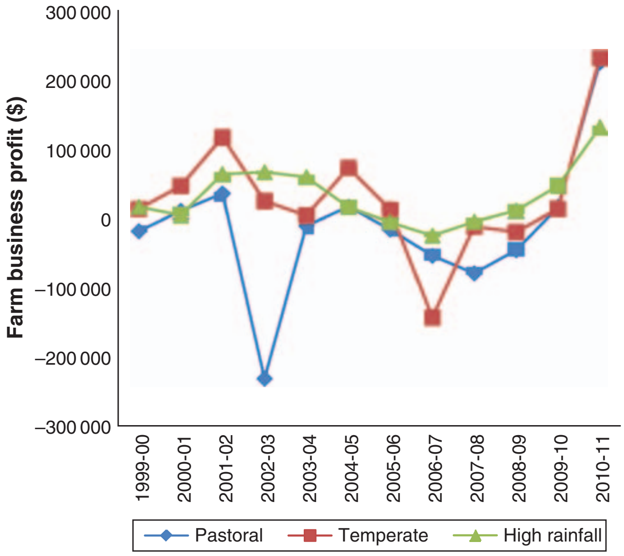


Figure 10.6: Farm business profit by zone for mixed-enterprise beef producers, 1999/00 to 2010/11. Source: ABARES (2012).

of feeder stock and high saleyard prices. This appears to be particularly true for cattle producers with larger herds, who can experience a fall in farm cash income due to herd rebuilding but at the same time undergo an increase in farm business profit due to an increase in on-farm cattle numbers and an increased value of farm inventory. In contrast, during the early drought period producers can actually have a substantial increase in receipts from beef cattle due to destocking and can record relatively high operating profits.

The profitability of southern beef enterprises can vary between the broadacre zones and between specialist and mixed-enterprise beef producers. Since 2000, specialist southern beef producers have made a loss in most years, particularly in the high-rainfall zone and the temperate areas (Fig. 10.5). Conversely, pastoral zone producers were making profits until drought in the early years of the 2000s resulted in substantial losses. Surprisingly, temperate and pastoral zone beef producers made a profit around the time of the 2005–06 drought due to a strong demand for feedlot cattle in those areas (Holmes *et al.* 2009). Profitability of specialist beef producers in the pastoral zone (Thompson and Martin 2011) was buoyed by South Australian producers experiencing excellent returns, while WA producers were still suffering from extended drought. Interestingly, the profitability of mixed-enterprise farm beef enterprises in the pastoral zone (Fig. 10.6) has been less erratic than that of the beef specialists. This could be a result of a higher dilution of costs such as labour among the other enterprises; labour has a significant impact on the cost structure of the farm business (McEachern *et al.* 2012). Mixed enterprises in all zones have made profits in the recent years of good seasonal conditions.

In 2009–10 the financial position of most southern beef producers was sound and most producers had high equity levels in their businesses. The 4% of producers that had relatively low equity (<70%) and negative farm cash incomes tended to be those in early development or under major expansion. On average, these producers were younger and relatively new entrants to farming (Thompson and Martin 2011).

In summary, productivity and profitability in southern Australia are very much subject to seasonal conditions. Drought has factored significantly in the performance of southern beef enterprises in the last decade. However, some southern beef cattle enterprises are more efficient and profitable than others, for reasons outlined in Chapter 18. The following section details the characteristics of the most profitable southern beef enterprises.

Characteristics of profitable southern beef enterprises

In many cases, a beef enterprise in southern Australia is one of several interrelated enterprises on a farm. The other enterprises, such as sheep, cropping or fodder production, can compete for resources (e.g. land area). However, they can also complement each other by sharing resources such as labour, assets and forage. The efficiency of the whole farm operation will depend on how well the enterprises are structured to achieve complementarities between enterprises (Chapter 20).

Some beef producers are benchmarked by various consultancy businesses (Chapter 18). The sample of producers participating in commercial benchmarking programs can be skewed towards the larger and more profitable producers in ABARES survey data (McEachern *et al*. 2012).

The Holmes and Sackett (2010) analysis of the southern beef industry situation in 2010 indicated that the most profitable beef producers made a paradigm shift from thinking in terms of per head production (price/head, sale weight/head) to per hectare returns. The key performance indicators of the top performing 20% of Australian and US beef producers from various consultancies are provided in Chapter 18.

Top performing southern beef producers usually have clear production objectives and make strategic decisions on supplementary feeding, marketing and genetics of cattle in order to achieve their superior returns. Manning (2004) suggested that stocking rate (and therefore pasture utilisation) is twice as important as herd fertility, which is twice as important as animal growth rates, which in turn are twice as important as carcass characteristics. Holmes and Sackett (2010) provided a priority ranking of management factors (Chapter 18).

Pasture utilisation has been identified (Black and Scott 2002) as an area of priority for southern beef producers (Chapter 15). Annual rates of pasture harvest are low at around 35%, with industry advisers suggesting that an increase to 50% would result in a doubling of enterprise profitability. Indeed, benchmarking data suggest that the top performing beef producers achieve higher productivity through a more efficient use of resources (e.g. pasture) as they produce more kilograms of beef per dry sheep equivalent (DSE) run and carry more DSE per hectare (after adjusting for rainfall).

The most profitable producers often adopt low- or nil-cost options to improve productivity and dilute costs (Holmes and Sackett 2010). Pasture utilisation is improved by aligning peaks in existing pasture growth (usually spring, in southern Australia) with times of high livestock demand (high nutrition to support lactation and rebreeding of females and growth of sale cattle). Choice of calving date and target sale date to meet the target market are important in this aspect (Chapter 18). Pasture utilisation can also be increased by optimising stocking rates, investing in quality genetics to make the most efficient use of pasture and reproduction traits, and improving infrastructure to enable good grazing management (Chapter 15).

Clearly, setting an appropriate stocking rate is an important determinant of farm profitability. For winter-dominant rainfall regions of southern Australia with annual rainfall between 400–800 mm, a target of 4 DSE/ha/100 mm rainfall above 250 mm for improved sown pastures is ideal (French and Schultz 1984; Holmes and Sackett 2010). The French–Shultz model (French and Shultz 1984) is considered to overestimate stocking rate for summer-rainfall regions. Regions outside the winter-dominant rainfall range need to look for regional benchmarks or increase stocking rate until cow body condition during midwinter (most limiting time of the year) is 2.5 in a spring calving enterprise (Holmes and Sackett 2006). Stocking rates need to be tailored for individual properties and should be set with a long-term view (Chapter 19). Some enterprises may be restricted by poor-quality land classes and never be able to reach advised stocking rate targets. Some enterprises may be limited by a producer's perception of increased risk (Holmes and Sackett 2010). Drought has occurred regularly in southern Australia and its negative impact on profitability is clear. Many producers believe that an increased stocking rate will make the farm less resilient to dry conditions. Benchmarking indicates that the most profitable beef producers in a good year also tend to be most profitable in drought years, by employing tactical management to lower supplementary feeding costs. That is, they run higher stocking rates in the good seasons but are quicker to reduce stocking rates when conditions get dry. This is opposed to running lower stocking rates in good years in anticipation of bad years, a custom of the average producer. Overall, achieving and maintaining stocking rates relies on deciding to destock and/or feed animals early enough during dry seasons that they can be sold in good condition, and ensuring the pasture base is not damaged from overgrazing.

The most profitable herds consistently sell heavier animals (Holmes and Sackett 2008). For example, selling more cull cows compared to light cull heifers and more heavy steers compared to weaners. In each case, there will be an impact on herd structure. A higher retention rate of replacement heifers will allow a higher proportion of lower-producing cows to be sold. This is not only more profitable but it will maintain a younger herd structure and higher reproductive efficiency (Manning 2004). Keeping slaughter cattle through an extra winter will affect winter stocking rate and can reduce the number of breeding cows that can be carried on the farm. If pasture availability allows, it is important that young animal growth potential is maximised relative to the efficiency of production per hectare. Growth rate is moderately heritable, ranging from 0.18–0.31 in Angus cattle (Angus Group Breedplan 2012), so direct selection on estimated breeding value will achieve good progress (Chapter 17).

Carcass characteristics attract premium prices in several high-quality export markets (Chapter 2). Achieving top dollar is important to many producers but the most profitable producers may receive neither the highest price nor highest individual animal performance. This is a consequence of higher stocking, where individual performance tends to decline even though production per hectare is optimised. The relationship between price received per kilogram and profits per hectare is not strong and this reflects the importance of the cost structure of the enterprise (McEachern *et al*. 2012). In southern Australia, producer benchmarking data indicate that 100% of beef can be produced for under $3.00/kg carcass weight and 80% of beef for under $1.46/kg. With 2012 beef prices, nearly all beef producers should have been making an operating profit before interest and tax (Holmes and Sackett 2010).

Cost of production is an important financial benchmark as it can explain 60% of the variation in profitability between beef herds (Holmes and Sackett 2006), with lower cost of production a key feature of profitable enterprises. Lower costs of production are achieved by a dilution of overhead costs with more units of production per unit costs, including labour (e.g. 17 610 DSE per labour unit compared to the 13 396 DSE per labour unit of the average benchmarked beef producer; Holmes and Sackett 2006). Improvements to labour efficiency can be made by promoting an easy-care production system with infrastructure suitable for sole operation, dedicating one labour unit to one large enterprise (within occupational health and safety considerations) and prioritising simpler methods of increasing pasture production (e.g. fertiliser application *v.* full pasture renovation) (McEachern *et al*. 2012). Another key to reducing cost of production is to reduce the need to supplementary feed cattle on a regular basis. The need to supplementary feed can be associated with a variety of factors: poor rainfall, poor alignment of peak pasture production with high animal requirements, poor soil fertility and poor management resulting in overgrazing (Holmes *et al*. 2009). As discussed, high-performing beef producers employ strategies such as growing and better utilising more pasture, strategically feeding cows to achieve target body condition scores by allowing them to lose and gain condition throughout the year, and timely destocking of cull and sale animals.

Profitable cattle trading enterprises (i.e. purchase and growing out of cattle for resale) tend to trade smaller mobs of cattle, be opportunistic and complement the management of the breeder herd by utilising surplus feed. Buying cattle in mobs of smaller numbers makes it easier to put more weight on them and wait out the market for better prices (McEachern *et al*. 2012). Trading cattle is also useful for transitioning between seasons if there is more pasture grown than can be utilised by the base breeding herd, or when restocking after a dry period.

ISSUES FACING THE SOUTHERN BEEF INDUSTRY

There are many issues facing beef producers in southern Australia. These include cost of production pressures (the cost:price squeeze), the profitability of alternate enterprises able to be run on the same land, restrictions associated with animal welfare and environmental sustainability, drought, disease and biosecurity. On the other hand, the predicted increase in world population from 6 billion to 9 billion and the increasing wealth of rapidly growing countries such as Brazil and China suggest that demand for meat will continue to rise (McRae 2011; Chapters 1, 4).

One key decision every producer faces is the scale of their beef operation, or whether to have a beef operation at all. Profitability of competing enterprises (Chapter 20) will be an important part of this decision, along with the producer's personal preferences, land capability and infrastructure. Beef enterprises are on land that can easily be used for alternate pasture-based enterprises, in particular sheep meat and wool. In many cases cropping may also be an alternate land use. In 2012, record sheep meat and lamb prices combined with the good season resulted in sheep enterprises doubling the profits of the beef and crop enterprises. However, over the long term, there has been little change in the ranking of benchmarked enterprises, with crop and dual-purpose sheep remaining the most profitable two enterprises. It must be remembered that there is more variation in profitability within enterprises than between them. Thus it is important to set strategies of change on both short- and long-term trends in profitability (McEachern *et al*. 2012).

Costs have increased faster than sale prices over many decades for all agricultural industries, and it is only through increased efficiency of production, assisted in some instances by technological advances, that producers have been able to maintain profits (Holmes and Sackett 2010). Labour efficiency is an excellent example of this, with producers increasingly needing to run more cattle with less labour. Motor bikes (instead of horses), more efficient hay and silage systems (large rather than small bales), better fencing, increased use of stock laneways and direct drilling of pastures have all assisted producers to be more labour-efficient. However, there is still concern over their ability to continue to increase efficiency ahead of rising costs. Fuel costs, fertiliser and labour are all costs that have risen well ahead of beef prices.

Increased productivity will also place more strain on the environment (Chapter 19). Increased awareness of the need for environmental sustainability will heighten costs as the community imposes either restrictions or greater environmental accountability. The production of methane (a greenhouse gas) and the possible need to mitigate against this, in addition to increasing energy costs as a result of concerns over global warming, will almost certainly place extra cost pressures on beef producers in southern Australia (Chapters 18, 19).

Similarly, while beef producers are aware of the need for high standards of animal welfare to ensure high levels of productivity, an increasing desire by the community to be involved in setting and upholding welfare standards (Chapter 13) will also almost certainly place extra cost pressures on beef producers. The recent suspension of live exports (DAFF 2011) from northern Australia to Indonesia (Chapter 12), while indirectly affecting southern producers, is a timely reminder of the importance of animal welfare standards in today's society.

While maintaining high standards in environmental care and animal welfare, there is increasing pressure to minimise chemical inputs to food-producing animals, both directly to the animals and indirectly to the pastures they are grazing and their supplementary feeds. Since the ban on hormonal growth promotants in the EU in 1988, their use in southern Australia has decreased. Also, beef producers have difficult decisions with respect to direct drilling and minimum till options. While direct drilling of pastures is environmentally more favourable, both from lower energy inputs and less degradation to the soil profile, it also requires increased use of chemicals (e.g. herbicides) to be an effective alternative.

Drought remains a constant challenge in southern Australia and current predictions are for more variable weather in the short to medium term (Cullen *et al.* 2009). Beef production occurs when animals are gaining weight, and long periods of supplementary feeding animals to maintain weight are very costly. Many producers respond to drought by reducing cattle numbers or by running lower than optimal stock numbers in normal years. Both options result in suboptimal production in the following non-drought years.

The more intensive nature of southern beef enterprises also means that animal health issues are common (Chapter 13). Beef production most commonly occurs in higher-rainfall areas and, under these conditions, parasites, bacteria and viruses can be a problem. Internal parasites have been identified as the number one health problem (Holmes and Sackett 2006). Other problems include bloat and metabolic diseases (e.g. grass tetany), but in the past decade both pestivirus and more recently theilieriosis appear to be increasing problems in beef herds in southern Australia.

In addition to endemic problems, the threat of the introduction of exotic diseases, in particular foot and mouth disease and bovine spongioform encephalopathy, remains a constant challenge to the industry in general. It is increasingly difficult to manage with the large and rapid movement of animals (Kennedy *et al.* 2006), animal products and people globally, and the move towards risk-based assessments for importations.

Several above-average seasons since 2010, following a decade of drier seasons, coupled with the belief that the southern beef industry is operated at a high level of efficiency and the continued predictions of both population and economic growth in the medium term, foster optimism in the industry.

REFERENCES

ABARE (2004) *Australian Beef Industry 04.2 Productivity*. <http://adl.brs.gov.au/data/warehouse/pe_abarebrs99001139/pc12892.pdf>.

ABARES (2012) *Farm Survey Data for the Beef, Lamb and Sheep Industries*. <http://www.daff.gov.au/abares/surveys> (accessed April 2012).

ABS (1908) *Year Book Australia*. Australian Bureau of Statistics, Canberra. <http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1301.01908?OpenDocument> (accessed August 2012).

ABS (2000) *Year Book Australia*. Australian Bureau of Statistics, Canberra. <http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1301.02000?OpenDocument> (accessed March 2012).

ABS (2005) *Year Book Australia*. Australian Bureau of Statistics, Canberra. <http://www.abs.gov.au/ausstats/abs@.nsf/Previousproducts/1301.0Feature%20Article232005?opendocument>.

Allen J (2002) Country report: Australia. In *Development Strategies for Genetic Evaluation for Beef Production in Developing Countries: ACIAR Proceedings* 108. Thailand. (Eds J Allen and A Na-Chiangmai) pp. 13–22.

Allworth B (2013) Personal communication. Professor Ruminant Health and Production, Charles Sturt University, NSW.

Angus Group Breedplan (2012) *Heritabilities of Traits in Angus Group Breedplan*. Angus Society of Australia, Armidale.

Anonymous (2004) *World Population to 2300.* UN, New York. <http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf> (accessed 26 September 2012).

Arthur PF, Hearnshaw H, Kohun PJ, Barlow R (1994) Evaluation of *Bos indicus* and *Bos taurus* straightbreds and crosses. 1. Post-weaning growth of steers in different environments. *Australian Journal of Agricultural Research* **45**, 783–794. doi:10.1071/AR9940783.

AUS-Meat (2012) *AUS-Meat Accreditation Listings*. AUS-Meat Ltd. <http://www.ausmeat.com.au/docs/AUS-MEAT%20Accreditation%20Listing.pdf>.

ALFA (2012) *ALFA/MLA Feedlot Survey April–June 2012*. Australian Lot Feeders Association. <http://www.feedlots.com.au/images/MR/mrjun12.pdf>.

Bailey PJ, Durand MR (1986) Beef production. In *The Pastoral Industries of Australia*. (Eds G Alexander and OB Williams) pp. 104–130. Sydney University Press, Sydney.

Barlow R, O'Neill GH (1978) Performance of Hereford and crossbred Hereford cattle in the subtropics of New South Wales: growth of first-cross calves to weaning. *Australian Journal of Agricultural Research* **29**, 1313–1324. doi:10.1071/AR9781313.

Black J, Scott L (2002) More beef from pastures: current knowledge, adoption and research opportunities. Final report prepared for Meat and Livestock Australia, No. SPB .004.

Breedplan (2013) Agricultural Business Research Institute (University of New England), Armidale. <http://breedplan.une.edu.au/>.

Bureau of Census and Statistics (Australia) (1949) *Official Year Book of the Commonwealth of Australia, no. 37, 1946–47.* Publications by the Commonwealth of Australia, Canberra.

Cammack KM, Thomas MG, Enns RM (2009) Review: reproductive traits and their heritabilities in beef cattle. *Professional Animal Scientist* **25**, 517–528.

Commonwealth Government of Australia (1922) *Meat Export Bounties Act.* <http://www.austlii.edu.au/au/legis/cth/num_act/meba1922111922272/>.

Cullen BR, Johnson IR, Eckard RJ, Lodge GM, Walker RG, Rawnsley RP, McCaskill MR (2009) Climate change effects on pasture systems in south-eastern Australia. *Crop and Pasture Science* **60**, 933–942. doi:10.1071/CP09019.

DAFF (2011) Australian government response to mistreatment of Australian cattle in Indonesian abattoirs. Department of Agriculture, Fisheries and Forestry, Canberra.

Davidson BR (1982) The economic structure of Australian farms. In *Agriculture in the Australian Economy*. 2nd edn. (Ed. DB Williams) pp. 29–54. Sydney University Press, Sydney.

Dear BS, Ewing MA (2008) The search for new pasture plants to acheive more sustainable production systems on southern Australia. *Australian Journal of Experimental Agriculture* **48**, 387–396. doi:10.1071/EA07105.

DPI Victoria (2009) *South West Farm Monitor Project*. Department of Primary Industries, Melbourne. <http://www.dpi.vic.gov.au/agriculture/about-agriculture/projects-and-activities/farm-monitor-projects/monitor-project/08-09>.

Dunn E (2005) Profitable beef production: more beef from pastures. In *Proceedings of the Australian Cattle Veterinarians Conference*, Gold Coast, Queensland.

Exton S (2012) Personal communication. Industry leader (beef products), Department of Primary Industries, Wagga Wagga, NSW.

French RJ, Schultz JE (1984) Water use efficiency of wheat in a Mediterranean-type environment. I. The relationship between yield, water use and climate *Australian Journal of Agricultural Research* **35**, 743–764. doi:10.1071/AR9840743.

Gosey J (2005) Crossbreeding: the forgotten tool. In *The Range Beef Cow Symposium*, Paper 32. <http://digitalcommons.unl.edu/rangebeefcowsymp/32> (verified 25 September 2012).

Hearnshaw H, Arthur PF, Johnston D, Stephenson PD (1995) Evaluation of Angus, Charolais and Hereford and first-cross cows. 1. Growth of progeny. *Australian Journal of Agricultural Research* **46**, 1231–1244. doi:10.1071/AR9951231.

Holmes C, Grainger C, Cusack P, Morris ST (2009) Dairy and beef production systems in Australia and New Zealand. In *Diseases of Cattle in Australasia*. (Eds T Parkinson, J Vermunt and J Malmo) pp. 13–23. New Zealand Veterinary Association Foundation for Continuing Education.

Holmes and Sackett (2006) *AgInsights: Knowing the Past, Shaping the Future*. Holmes and Sackett and Assoc., Wagga Wagga, NSW.

Holmes and Sackett (2008) *AgInsights: Knowing the Past, Shaping the Future*. Holmes and Sackett and Assoc., Wagga Wagga, NSW.

Holmes and Sackett (2010) Southern beef situation analysis. Final report for Meat and Livestock Australia. Project No. B.COM.0255. <http://www.mla.com.au/About-the-red-meat-industry/Industry-overview/Cattle>.

Hooper S (2010) Australian beef: financial performance of beef cattle producing farms 2007–08 to 2009–10. Australian Bureau of Agricultural and Resource Economics, Canberra, 10.1

Hunter RA (2010) Hormonal growth promotant use in the Australian beef industry. *Animal Production Science* **50**, 637–659. doi:10.1071/AN09120.

Jenkins TG, Ferrell CL (1985) Energy requirements for maintenance of beef cattle differing in genetic potential for mature size and milk production. Beef Research Program, Roman L. Hruska, US Meat Animal Research Centre. Paper No. 46.

Kennedy D, Sergeant E, Whan I, Freer B, Cameron A (2006) A review of the structure and dynamics of the Australian beef industry. A report to the Department of Agriculture, Fisheries and Forestry, Canberra. <www.daff.gov.au/__data/assets/pdf_file/.../*beef*-movement-ead.pdf>.

Makeham JP, Christiansen TJ, Malcom LR (1979) *Coping with Change*. Gill Publications, Armidale, NSW.

Manning R (2004) The changing face of beef production: the drivers of a profitable beef production system. In *Proceedings of the Association of Cattle Veterinarians*, Grindewald, Tasmania, pp. 34–42.

McEachern A, Francis J, Brown D (2012) *AgInsights: Knowing the Past, Shaping the Future*. Holmes and Sackett and Assoc., Wagga Wagga NSW.

McKiernan WA, Wilkins JF, Barwick SA, Tudor GD, McIntyre BL, Graham JF, Deland MPB, Davies L (2005) CRC Regional Combinations Project: effects of genetics and growth paths on beef production and meat quality: experimental design, methods and measurements. *Australian Journal of Experimental Agriculture* **45**, 959–969. doi:10.1071/EA05061.

McKiernan WA, Wilkins JF, Irwin J, Orchard B, Barwick SA (2009) Performance of steer progeny of sires differing in genetic potential for fatness and meat yield following post-weaning growth at different rates. 2. Carcass traits *Animal Production Science* **49**, 525–534. doi:10.1071/EA08267.

McRae T (2011) *Australian Cattle Industry Projections 2011*. Meat and Livestock Australia. <http://www.mla.com.au/Prices-and-markets/Trends-and-analysis/Beef/Forecasts/MLA-Australian-cattle-industry-projections-2012> (accessed August 2011).

McRae T (2012) *Australian Industry Cattle Projections 2012*. Meat and Livestock Australia. <http://www.mla.com.au/Prices-and-markets/Trends-and-analysis/Beef/Forecasts/MLA-Australian-cattle-industry-projections-2012> (accessed July 2012).

MLA (2011) *Australian Red Meat 2000–2010: A Turbulent Decade, a Vibrant Industry*. Meat and Livestock Australia. <http://www.mla.com.au/Prices-and-markets/Trends-and-analysis> (accessed November 2011).

Newton Turner H, Donelly FB, Booth PC, Whitely KJ (1986) Wool production. In *The Pastoral Industries of Australia*. (Eds G Alexander and OB Williams) pp. 61–81. Sydney University Press, Sydney.

Nossal K, Sheng Y, Zhao S (2008) Productivity in the beef cattle and slaughter lamb industries. ABARE Research Report No. 08.13 for Meat and Livestock Australia, Canberra. <http://adl.brs.gov.au/data/warehouse/pe_abarebrs99001592/rr08.13_productivity_beef_lamb.pdf> (accessed November 2011).

Peel LJ (1986) History of the Australian pastoral industries. In *The Pastoral Industries of Australia*. (Eds G Alexander and OB Williams) pp. 41–60. Sydney University Press, Sydney.

Pitchford W, Graham J (2010) Maternal productivity project: summary. *Maternal Journal* (Beef CRC).

Reeves G (1982) The Australian beef industry: a perspective on the demand and supply forces in domestic and overseas markets. Occasional Paper No. 63. Papers on the Australian Beef Cattle Industry. <http://adl.brs.gov.au/data/warehouse/pe_abarebrs99000114/op63_aust_beef_cattle_industry.pdf> (accessed July 2012).

Sturgess NH, Malcom LR (1986) Management economics in the pastoral industries. In *The Pastoral industries of Australia*. (Eds G Alexander and OB Williams) pp. 347–367. Sydney University Press, Sydney.

Thompson T, Martin P (2011) Australian *Beef: Financial Performance of Cattle Producing Farms, 2008–09 to 2010–2011*. Australian Bureau of Agriculture and Resource Economics and Sciences <daff.gov.au/abares/publications> (accessed June 2012).

Walmsley B, Parnell P (2010) Defining and modelling maternal productivity. *Maternal Journal* 2 (Beef CRC). <http://www.beefcrc.com/documents/publications/maternal-journals> (verified April 2012).

Wolfe E (2009) *Country Pasture/Forage Resource Profiles: Australia*. Food and Agriculture Organization of the UN. <http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Australia.pdf> (verified 3 August 2012).

11 Australian feedlot industry

J.B. Gaughan and M.L. Sullivan

BRIEF HISTORY FROM 1960

Feedlots are defined as 'a confined yard area with watering and feeding facilities where cattle are completely hand fed or mechanically fed for the purpose of production' (MLA 2002). Commercial feedlotting is undertaken in all states (Fig. 11.1). Feedlots are usually located in close proximity to grain-growing areas, because feed accounts for 60–70% of the costs associated with finishing cattle in a feedlot. In 2012 ~2.45 million head (35%) of beef cattle were finished in feedlots, and ~65% of these were exported. The majority of feedlots are located in the eastern states, with Queensland having the largest number of feedlots, and over 50% of feedlot space (Fig. 11.1).

Feedlotting commenced in the USA during the 1920s, but it was not until the 1950s that Australia began experimenting with the concept. In the early 1960s commercial feedlotting started on the Darling Downs in Queensland, initially as a method for utilising the vast supplies of cheap grain that were available at that time (Chappell 1993). A major stimulus for the expansion of the industry into NSW was the drought of 1965–66. During this period the NSW Department of Agriculture recommended that farmers with grain surplus switch from maintenance feeding of cattle to production feeding (Chappell 1993). Further expansion was undertaken in the late 1960s and early 1970s to meet demand from overseas customers for a specifically tailored, consistently high-quality meat. By the early 1970s there were 30 feedlots in Australia with >1000 head capacity (SSCRRA 1992), and a few with a capacity of ~20 000 head (Tucker *et al.* 1991). Some of the early commercial feedlots, the year of their establishment and location are listed below:

- Wainui–established 1962 (Qld);
- Mungala–established 1962 (Qld);
- Aronui–established 1964 (Qld);
- Kerwee–established 1965 (Qld);
- Gurley Station–established 1969 (NSW);
- Charlton–established 1970 (Vic);
- Zeniciku-Tancred Pastoral Co.–established 1970 (Qld).

Despite a setback in expansion in 1975 when access to the Japanese market temporarily closed, the Australian feedlot industry had grown to 830 feedlots by 1996 when the National Feedlot Accreditation Scheme commenced. Since then, a significant number of mainly small lots have ceased operations or not achieved nor sought accreditation. As a result, the number of accredited feedlots (i.e. able to market grain-fed beef) decreased to 710 by June 2000 and further decreased to 575 by March 2004. In 2012, there were ~700 accredited feedlots in Australia (Fig. 11.2). Fluctuations in the number of feedlots and cattle capacity over the last 50 years are presented in Table 11.1. Accurate historical data is difficult to obtain as there were several reporting bodies, and for a time feedlots with <50 head did not require a licence (Chappell 1993). Data obtained from 2000 onwards is deemed to be robust.

In contrast to the fluctuations in the number of feedlots, carrying capacity had risen to 926 000 head as at 31 March 2004, ~1.26 million head by March 2010 and 1.32 million by March 2012. However, carrying capacity

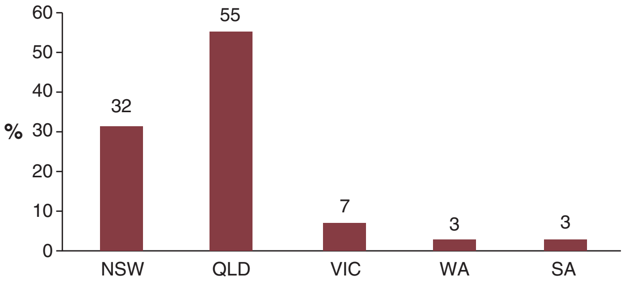


Figure 11.1: Australian national feedlot cattle percentages 'on feed' within each state as at March 2011. Source: FutureBeef (2012).

and numbers on-feed are rarely equal. For example, at the end of March 2004 numbers on-feed were reported to be 666 000 head (72% of total carrying capacity), during March 2009 numbers on feed were 677 085 (60% capacity) and in March 2010 numbers on feed were 711 198 (56% capacity) (ALFA 2010). For the quarter ending September 2012 the number of cattle on feed in Australia was 717 145 (57% capacity) (ALFA 2012a).

Table 11.1: Feedlot numbers and cattle capacity

Year	Number of feedlots	Capacity
Prior to 1966	7	Unknown
1966–70	11	Unknown
1971–75	19	Unknown
1976–80	26	~140 000[1]
1981–85	67	~190 000[1]
1988	–	180 000[2]
1990	848[1]	485 000[3]
1992	1030	534 000[3]
1996	830	–
2006	692 (accredited feedlots)	1.10 million[4]
2011	~700 (accredited feedlots)	1.28 million[4]
2012	~700 (accredited feedlots)	1.32 million[5]

Source: 1. Tucker *et al.* (1991); 2. Chappell (1993); 3. SSCRRA (1992) (based on 631 feedlots); 4. ALFA (2012a); 5. Estimated.

MARKETS

The markets targeted by the feedlot sector are determined by several factors including the value of the Australian dollar (relative to the US dollar), market (consumer) demand in Australia and overseas, local and international availability of beef, import tariffs and the global financial situation. In 2012 the Australian industry was highly dependent on overseas markets for its finished products, with 65% of feedlot beef being exported and the remaining 35% being marketed domestically (MLA 2012a).

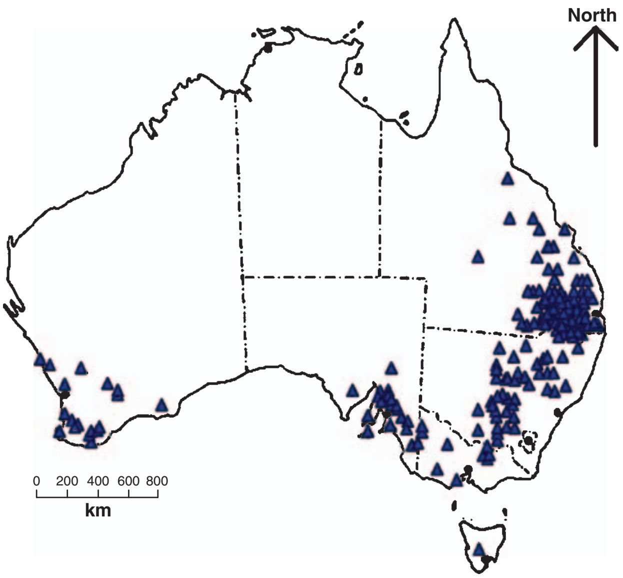


Figure 11.2: Approximate locations of accredited feedlots.

Tariffs

Australia's beef exports face trade barriers in several countries. These barriers commonly take the form of tariffs and/or tariff rate quotas. Essentially these are a tax levied on goods transported from one customs area to another (MLA 2012b).

A tariff rate quota is a quantity limit on imports below which a reduced or in-quota tariff is charged on imports. Where imports exceed the tariff rate quota, the level of imports above the limit is charged a higher or above-quota tariff. The tariff percentages applying to Australian exports in 2012 are shown in Tables 11.2 and 11.3. These tariffs can significantly impact upon exports as they are an extra cost for the importer, and can play a role in the decision-making process for the importation of goods (MLA 2012b). The main export markets for feedlot beef are Japan, Korea and the USA; these markets also take grass-fed and manufacturing beef (Chapters 5, 8). Other markets of importance to the beef industry as a whole include south-east Asia (Chapter 7), Russia, the EU and the Middle East.

Market specifications

Beef markets have particular specifications that allow producers to target animals for a specific market (Chapter 3). The market specifications are classified into minor and major market specifications, as shown below (adapted from Andrews and Little 2007).

Table 11.2: Tariffs applying to Australian exports

Country	Bound tariff[1] (%)	Applied tariff (%)
Canada (above quota)	26.5	26.5
China	18.6	12–25
EU	100[2]	In quota 20% customs duty Above quota 12.8% + 141.4–304.1 Euro/100 kg
Indonesia	50	0–5 (0% for most tariff lines by 2020 under AANZFTA)
Japan	50	38.5 (special safeguard of 50%)
Mexico	45	20–25
Philippines	40	10 (0% by 2012 under AANZFTA)
Russia	Not a WTO member	In quota 15%, but not less than 0.2 euro/kg Above quota 50%, but not less than 1 euro/kg
South Korea	40	40
Taiwan ('other quality' beef)	29[2]	NT $10/kg
Thailand	51	24 (0% by 2020 under TAFTA)
USA (above quota)	26.4	In quota 0% Above quota 26.4% (0% by 2022 under AUSFTA)

1. Bound tariffs are those agreed to under GATT or WTO. They represent commitments not to increase tariffs above the listed rates, i.e. the rates are 'bound'.
2. Estimated tariff equivalent (average across tariff lines).
AANZFTA = ASEAN-Australia-New Zealand FTA; TAFTA = Thailand-Australia FTA; AUSFTA = Australia-US FTA.
Source: MLA (2012b).

MAJOR MARKET SPECIFICATIONS

- Weight (live or carcass).
- Fat (P8 fat depth or score).
- Sex.
- Age (dentition).

MINOR MARKET SPECIFICATIONS

- Breed.
- Lifetime traceability.
- Accreditation or other eligibility requirements.
- Muscle score.
- HGP (hormonal growth promotants) status.
- Meat colour.
- Fat colour.
- Fat distribution.
- Meat/carcass pH.
- Butt shape.

Each export and domestic market has specific requirements that are subject to change over time. Specifications for the major export markets and the Australian domestic market during 2012 are shown in Table 11.4.

Market statistics

Between 2000 and 2012 the Australian beef industry was subject to several challenges, including drought and an unstable Australian dollar. In 2001, the low Australian dollar relative to the US dollar (AUD$ < US$0.50) led to an increase in beef exports (MLA 2011). In 2003,

Table 11.3: Tariff quotas that apply to Australian exports (2012)

Country	Australia's country-specific tariff quota (t)	In-quota tariff (%)
Canada	35 000 (calendar year)	0
EU (high-quality beef)	7150 (fiscal year)	20
EU (grain-fed beef)	Australia has shared access with the USA (and other potentially eligible suppliers) to a 20 000 t quota (fiscal year)	0
USA	408 214 (calendar year) expanding to 448 214 by 2022 under AUSFTA	0
Russia	Australia has shared access along with other eligible suppliers to a 428 300 t frozen beef quota (calendar year) and a 1000 t chilled quota (calendar year)	15, but not less than 0.2 euro/kg

Source: MLA (2012b).

Table 11.4: Australian beef cattle market specifications – export and domestics markets

Australian beef cattle markets specifications						
	Export				Domestic	
Specifications	120 day feeder steers (Japan Korea short-fed)	Jap steers	Jap feeder steers (Japan/Korea long-fed)	EU	Local butcher	Supermarket
Breed content	British or European *x* British bred, max. 50% *Bos indicus*	No breed or age restrictions	Not breed restricted but suited to Angus, Shorthorn and British crosses	No breed restrictions	No breed restrictions	Some market sectors have breed restrictions (i.e. Bos indicus content)
Sex	Steers	Steers	Steers	Steers or heifers	Steers or heifers	Steers or heifers
Diet	Grain-fed 120–150 days	Grass-finished	Grain-fed 150–350 days	Grass- or grain-fed	Grass- or grain-finished	Grass- or grain-fed (max. 70 days on grain) or grain-assisted
Carcass weight	280–400 kg (average 350–360 kg)	300–420 kg	350–450 kg	260–419 kg	160–220 kg	200–280 kg
Dentition	Up to 4 permanent teeth	6+ teeth will be discounted	Liveweight entry to feedlot 350–500 kg	Max. 4 permanent teeth	0–2 teeth	0–2 teeth (preferably 0 teeth)
P8 fat depth	3–12 mm (fat score 2 or 3)	7–22 mm	Max. 12 mm (fat score 3)	7–17 mm	4–8 mm	5–16 mm
Other requirements			Highly marbled carcass desiredPreference for lifetime traceability or vendor-bred cattle	No HGPProperties must be EU accredited		

Adapted from Andrews and Little (2007).

continued drought in Australia significantly reduced beef production which reduced export capacity (MLA 2011). However, confirmation of BSE (bovine spongiform encephalopathy) in the USA in late 2003 resulted in Japan banning the importation of US beef (Chapter 8). Australia was able to capitalise on this by supplying more beef into Japan. This had a positive flow-on effect for Australian cattle prices, and meat products. The destinations of Australian feedlot cattle (domestic or export) for the period 2005–10 are presented in Table 11.5. The total volume of all Australian beef and veal exports and country of destination for 2011 are shown in Table 11.6.

Recent market highlights and future directions

Global beef demand is forecasted to expand over the next 25 years, due largely to population and income growth particularly in Asia. In contrast, global beef supplies are forecast to remain stable, resulting from a limitation in land and water availability and an increase in grain prices. This may limit global beef consumption and increase the cost of beef products (Hansen 2012).

There are some significant challenges to the Australian beef industry and subsequently the Australian feedlot industry. First, the predicted 15% (330 000 t) increase in Australian beef supply over the five years 2011–16 is unlikely to have much impact on global trade (Chapter 4). Second, the high Australian dollar relative to the US dollar between 2010 and 2013 had a negative impact on Australia exports by making them less competitive against other countries, notably the USA, and predictions are that the Australian dollar will trade above US$1 well into the mid 2010s (this is particularly important for the feedlot sector). Third, the reintroduction of South American beef exports onto the global market may have an impact on some of the export markets targeted by Australia (Hansen 2012). For example, Brazil may export cull

Table 11.5: Intended market destination for feedlot cattle (no. of cattle)

Quarter ending	Domestic	Export	Unknown
March 2005	255 661	576 832	23 530
June 2005	314 369	550 989	13 555
September 2005	246 095	528 984	17 146
December 2005	230 401	478 066	25 891
March 2006	293 098	579 074	23 504
June 2006	308 634	576 905	54 558
September 2006	287 942	557 408	35 931
December 2006	298 621	579 299	30 900
March 2007	263 343	578 529	31 397
June 2007	267 664	588 623	13 738
September 2007	205788	461 719	13 015
December 2007	160 224	417 650	6598
March 2008	184 367	416 860	2797
June 2008	175 146	500 993	11 641
September 2008	164 857	465 138	5720
December 2008	188 790	533 430	888
March 2009	225 784	449 729	2292
June 2009	240 965	497 657	4923
September 2009	227 223	513 958	1871
December 2009	234 475	506 187	29 561
March 2010	247 622	452 104	11 472
June 2010	247 314	508 834	34 624
September 2010	291 758	457 690	16 370

Source: MLA (2010b).

cow beef to the USA. This would reduce the value of export-grade manufacturing beef from Australian cull cow by up to 40% (IBISWorld 2012). This would probably have little impact on feedlot beef exports. Brazil has the capacity to produce beef at relatively low cost compared to Australia and has an expanding feedlot sector (Chapter 6); however, increased domestic demand for beef and changing labour demands have resulted in increased labour costs, which may hinder exports. Furthermore, feed costs are linked to global supply and demand and this is pushing up costs for cattle feed. The presence of foot and mouth disease and a confirmed case of BSE in 2012 will continue to constrain exports from Brazil, as will the increasing domestic demand for beef.

Throughout the 1990s and 2000s, Australia had three main export markets which accounted for ~80% of export volume. These markets were Japan, the USA and South Korea. The feedlot sector provided a substantial amount of the meat exported to Japan and South Korea. The US market was mainly for manufacturing beef, although some high-quality feedlot beef was also exported to the USA.

Japan

In 2010, Australian beef exports to Japan made up 34% of Japan's total beef imports. In 2011/12 these imports fell 4% as a result of the tsunami and subsequent nuclear reactor meltdown. The Australian industry is expected to face several future obstacles to marketing beef into Japan. These include increased competition from the USA and other countries, volatility in the Japanese economy, and

Table 11.6: Export volumes for chilled and frozen Australian beef and veal products ('000 t)[1]

Destination	2008	2009	2010	2011	2012[2]	2013[2]
Japan	364.3	356.6	356.2	342.2	325.0	325.0
USA	234.8	251.5	185.0	167.8	250.0	280.0
Korea	127.2	115.5	124.1	146.3	105.0	100.0
Russia	73.0	15.2	56.7	55.9	55.0	60.0
Other South-East Asia[3]	29.8	34.1	40.4	47.6	49.5	52.5
Indonesia	33.0	51.8	48.4	39.6	29.0	27.0
Taiwan	27.1	31.3	30.8	36.7	35.0	35.0
Middle East	13.0	15.8	24.3	31.9	32.0	34.0
EU	11.9	9.2	9.8	12.8	15.0	17.0
Canada	8.5	12.3	6.9	10.1	12.0	15.0
China and Hong Kong	5.9	12.8	12.6	16.6	13.0	15.0

Source: McRae (2012).

[1] These values are inclusive of all exports, not just from feedlots.

[2] Forecast numbers.

[3] Philippines, Singapore, Malaysia, Thailand.

the high Australian dollar. The US competition can be attributed to the increase in the age requirement of exported beef, from cattle that were <21 months old to cattle <30 months old. This has the potential to increase exports of US beef to Japan by up to 25% (MLA 2012a). Most of the Australian exports to Japan were derived from feedlot beef.

South Korea

The South Korean–USA free trade agreement (FTA) was signed in 2011 and will remove 40% of tariffs on US beef exported to South Korea over 15 years. The tariff rate for US beef will decrease by 2.7% each year, starting in 2012. This will give the USA a key advantage in the South Korean market (Office of the USTR 2012). The continued lack of a reciprocal agreement between South Korea and Australia would have a negative impact on beef exports to South Korea. The future for Australian exports looks set to decline, with beef exports estimated to decrease 4% to 143 000 t by 2016 (Cooper 2012). This could have a significant impact on feedlot production in Australia if alternative markets are not located.

USA

The USA remains Australia's second-largest importer of beef and is an important market for Australian manufacturing beef. Only small amounts of feedlot-sourced beef are exported to the USA. In 2011 Australian beef and veal exports to the USA were 9% lower than for 2010, the lowest annual total since the late 1960s. This was largely due to the poor state of the US economy and the high Australian dollar (MLA 2012a). Australian beef exports to the USA are expected to increase substantially between 2012 and 2017, however, this will be influenced by the US economy, the value of the Australian dollar, and output from New Zealand and Uruguay (Hansen 2012; Cooper 2012).

Russia

Russia was Australia's fourth-largest beef export market in 2011 and was the world's second largest importer of beef products (MLA 2012a). Beef importation into the region was expected to increase 12% (75 000 t) over the period 2011–16 due to income-driven demand growth, restricted growth in local supplies and strict import controls on alternative meats. Any increase will be shared by Argentina and Brazil, with Australia's share expected to decline by 20 000 t to 35 000 t (Hansen 2012). Little or no feedlot-derived beef has been exported to Russia in the past.

Taiwan

The 2011 export market was strong with Taiwan having a record volume of 36 748 t, an increase of 19% from 2010. This was attributed to a reduction in competition from the USA resulting from continuing food safety issues. The previous yearly record for Australian beef exported to Taiwan was set in 1992 (36 500 t) (MLA 2012a). Beef consumption in this region was predicted to increase 9% from 2011–16, driven by high population and income growth (Hansen 2012). This market has potential for significant uptake of feedlot beef, but up to 2012 there were insignificant exports to this market.

EU

The strength of the export market to the EU reduced significantly in the 2000s due to financial turmoil in the region. The fragile economic situation and low consumer confidence combined with the weak euro impacted on the demand for beef products. In January 2012, the euro dropped to its lowest recorded level against the Australian dollar largely due to financial debt issues in the EU. The low level of the euro was expected to continue and the situation has the potential to deteriorate (MLA 2012a), which would further restrict exports from Australia.

One positive change was the introduction of the tariff-free, grain-fed beef quota in 2011. Following its introduction there was a significant increase in Australian beef exported to the EU (from 8146 t in 2009/10 to 13 403 t in 2011/12). Contributing to this was an increase of the grain-fed quota to 48 200 t/year, and the introduction of a first-come-first-served import system. Under this system the product is presented at the point of entry and is received into the EU with no duty until the quota is fully utilised. This removes any speculation on the quota (ALFA 2012b). Despite this, beef consumption in the EU was expected to increase by only 1% between 2011 and 2016 due to low economic growth and a falling population in the region (Hansen 2012).

Middle East

The strong economic growth and the escalating population of the Middle East, and its limited ability to produce its own beef, have allowed the export market to significantly expand (MLA 2012a). Australian exports to the Middle East were expected to increase by 50 000 t (91%) to 105 000 t from 2011–16, driven by a strong population and income growth in the region (Hansen 2012). In 2012 this market was of minor importance to the feedlot sector.

Exports to less traditional destinations rose in 2012, with greater amounts of grain-fed beef sent to South-East Asia, the Middle East and Europe. Together, these markets utilised 9105 t of feedlot beef (Myers 2012).

Australian domestic market

The domestic beef market is the largest single market for Australian beef, accounting for about one-third of all beef production (Gleeson *et al*. 2002). The generally strong domestic beef market declined in 2011 with restricted cattle supplies and slow retail demand, despite intense competition of prices between the two largest supermarket chains contributing to competitive prices for the consumer. With the downturn in the export market due to the high Australian dollar and the decline in exports to the USA and Japan, it would be expected that the Australian beef market would be overcome with surplus product but the smaller export markets utilised the excess beef products (MLA 2012a). The highly favourable season in Australia in 2011 also saw the demand and prices for young cattle improve, which forced Australian processors to compete with producers and feedlot operators for the tight supply of suitable cattle (MLA 2012a).

The production volume of beef and veal in 2011 was 2.15 million t. The total volume of beef and veal products remaining in the Australian market was estimated at 728 000 t, a decrease of 3% from 2010 volumes but higher than both 2008 and 2009 (MLA 2012a). Domestic beef consumption was predicted to increase 12% (87 000 t) in the period 2011–16. The domestic market has advantages over the export market in that there is little influence of the Australian dollar, no market access issues, simple logistics and high per capita beef consumption (Hansen 2012). However, beef needs to compete domestically with chicken, pork and lamb. Market stability requires a strong domestic market, and a considerable effort has gone into the promotion of beef in the domestic market. For long-term economic stability the domestic market needs to consume at least 50% of production.

QUALITY CONTROL IN FEEDLOTS

National Feedlot Accreditation Scheme

The National Feedlot Accreditation Scheme (NFAS) commenced in 1994, and all accredited feedlots are required to be part of it. The NFAS was developed in response to the necessity of Australian feedlots to adopt quality assurance principles to meet the expectations of beef markets, government and the community in relation to animal welfare, environment, meat quality and food safety. Since 1995, only accredited feedlots are able to sell grain-fed beef (Firrell 2011), whereas non-accredited feedlots market grain-assisted beef. The classification of grain-fed beef is ensured by the use of NFAS delivery dockets, which are a requirement for identification of accredited grain-fed beef and grain-fed young beef (Firrell 2011). The scheme makes certain that all accredited feedlots are audited each year to guarantee compliance with food safety, product integrity, environment and animal welfare legislations (AUS-MEAT 2010). The mission of the NFAS is to ensure that the Australian beef feedlot industry has a feedlot management program to:

- enhance the marketing prospects for grain-fed beef by raising the integrity and quality of the product;
- establish a viable mechanism for industry self-regulation;
- maintain the image held by the community of feedlots, particularly relating to the environment and animal welfare matters.

The objective of the NFAS is to develop and maintain a quality system for feedlots which impacts on product quality and acceptability and for which lot feeders maintain full responsibility.

To be accredited, a feedlot operator must:

- have documented procedures in place for the feedlot which meet the requirements of the industry standards;
- maintain records that those procedures have been adhered to for all cattle prepared at the feedlot;
- undergo a third-party audit of these procedures, records and facilities at the feedlot.

The NFAS standards comprise five modules which include:

1. quality management system – training, internal auditing and corrective action, quality records, document control and chemical inventory;
2. food safety management – property risk assessment, safe and responsible animal treatment, fodder crop, grain and pasture treatments and stock foods, preparation for dispatch of livestock, livestock transactions and movements;
3. livestock management – livestock identification, livestock husbandry and presentation, livestock transport, animal welfare, excessive heat load, biosecurity, incident reporting and contingency planning;

4. environmental management;
5. product integrity – NFAS delivery documentation and feedlot rations.

Codes of practice incorporated into the NFAS standards include *National Guidelines for Beef Cattle Feedlots*, *Model Code of Practice for the Welfare of Animals: Cattle* (2nd edn) and *National Beef Cattle Feedlot Environmental Code of Practice* (AUS-MEAT 2010).

To maintain NFAS registration, the enterprise must employ or engage a minimum number of quality assurance (QA) officers depending on feedlot capacity (Table 11.7). The role of a QA officer is to ensure that all cattle recorded on an NFAS delivery document fulfil the AUS-MEAT minimum standards for grain-fed beef and certify that all NFAS delivery documents are accurate and signed (AUS-MEAT 2010).

Consistency of product

Consistency of product is established in part by feeding requirements. Feeding requirements for grain-fed young beef are: 0–2 tooth, 60 days on feed for heifers; 70 days for steers. For grain-fed the requirements are: up to 6 teeth, 100 days on feed (Firrell 2011). However, individual animal and breed differences will affect aspects such as fat distribution, marbling and fat depth (Chapter 2).

Self-regulation

All NFAS-accredited feedlots are audited by an independent third party each year. These audits are conducted by AUS-MEAT. The Australian Lot Feeders Association (ALFA), as a peak industry body, identifies areas of potential concern; these may be public perception issues dealing with welfare, or improved traceability required by export customers. New rules and standards come into force after they have been approved by the Feedlot Industry Accreditation Committee (FLIAC) (Firrell 2011). Accredited feedlots (and suspended feedlots) are notified of changes to rules and standards via NFAS Circulars. For example, NFAS 01/2009 dealt with *Clarification of the Method Used for Calculating Days on Feed (DOF).*

Table 11.7: Number of QA officers required, by feedlot size

Feedlot size	Minimum no. of QA officers
Up to 1000 head	1 person
1001–10 000 head	2 people
10 001–30 000 head	3 people
>30 000 head	4 people

Source: AUS-MEAT (2010).

Standard cattle units

A standard cattle unit (SCU) is defined as an animal of 600 kg liveweight at the time of exit (turnoff) from the feedlot (Skerman 2000). The SCU allows the stocking capacity of the feedlot to be calculated on the actual liveweight of the cattle, rather than the number of head. The SCU is based on the consideration that manure production increases with liveweight (Skerman 2000).

The use of SCU allows all feedlots to be compared on the same basis. Specific conversion factors create adjustments in the number of head that a feedlot is permitted to house depending upon the actual liveweight of the cattle (DPI Vic 2012). The conversion factors used in the SCU are based on metabolic liveweight of the cattle (liveweight$^{0.75}$) (Table 11.8).

The total liveweight for a feedlot can be determined by using the maximum average liveweight that will occur at any time throughout the year. This is generally the average liveweight of the cattle on feed at any time. If the weight is lower than the weights listed in Table 11.8 then the weight must be rounded up to the next weight category (Government of South Australia 2006).

The number of SCU at the feedlot can thus be calculated by:

$$\text{SCU} = \text{N} \times \text{Cs}$$

where SCU = number of standard cattle units, N = number of cattle at the feedlot, Cs = conversion factor of average liveweight to standard cattle units (Government of South Australia 2006).

An example calculation of the SCU is a maximum liveweight of 420 kg is rounded to 450 kg, which is

Table 11.8: SCU adjustments for liveweights of 350–750 kg

Approximate liveweight (kg) at turnoff	No. of SCU
750	1.18
700	1.12
650	1.06
600	**1.00**
550	0.94
500	0.87
450	0.81
400	0.74
350	0.67

Source: DPI Vic (2012).

0.81 SCU. If the feedlot is permitted to have 1000 SCU the equivalent number of 420 kg cattle is 1235 (Government of South Australia 2006).

Meat Standards Australia

Meat Standards Australia (MSA) allows for differentiation between beef products in the market (Chapters 2, 3). The MSA system allows the eating quality of individual beef muscles to be accurately predicted (MLA 2012c). The MSA grading system was introduced in 1996 and is based on detailed consumer research that investigated the persistent decline in beef consumption (Polkinghorne *et al.* 2008). The investigation involved over 86 000 consumers and over 603 000 beef samples. It identified reduced consumer knowledge of cuts and cooking techniques and the degree of quality variation in beef products available in the market. It was believed that consumers would purchase more beef products, even at higher prices, if the product was reliable (MLA 2012c; Polkinghorne *et al.* 2008). Current MSA grading data states that 2.265 million head of cattle are MSA-graded, with 94.2% of these carcasses MSA-compliant (successful in obtaining a MSA grade) (Condon 2013).

The MSA grading system provides consumer assurance of eating quality at three specific grades – MSA 3, 4 and 5 – and a specifically 'cut-matched' cooking method designed to assist consumers. The grading system can be related to price and can assist in developing consumer acceptance of beef. Detailed testing protocols were utilised in developing the system: each participant involved in the investigation (over 86 000 consumers across eight countries) tested seven samples from varying cuts and cooking methods, including a low- and high-quality product, in specialised taste-testing cubicles. The consumer gave each sample a score out of 100 based on the following weighting – tenderness 40%, juiciness 10%, flavour 20% and overall liking 30% – and an overall opinion on whether the sample was of 'unsatisfactory', 'good every day', 'better than every day' or 'premium' quality. This information was used to calculate the MSA grades, which were statistically tested. The consumer standards are continually reassessed through taste-testing and an independent auditing program to maintain consistent standards and consumer satisfaction (MLA 2010b).

Any abattoir that processes cattle for MSA must be licensed. To become licensed, particular points of the abattoir must be assessed as there may be an impact on the eating quality of the final product (MLA 2012c).

These criteria include:

- livestock arrival areas must prevent injury or stress to the animal;
- slaughter floor and chillers must meet requirements for pH and temperature of the carcass (pH <5.71 and temperature <12°C);
- trial carcass grading must be conducted to predict prospective eating quality outcomes;
- the boning room must be equipped for appropriate packing and labelling requirements (MLA 2012c).

The grading process in the abattoir (Chapter 2) involves examining the following aspects of the carcass: weight, sex, hump height, hanging method, ossification, marbling, rib fat, pH and temperature and meat colour. The MSA grading system encourages quality assurance from the paddock to the plate and allows consumers to purchase beef products with confidence and the knowledge that the product has been assessed and graded according to a specific system that guarantees quality (MLA 2012c). To supply MSA-graded meat, the producer needs to be MSA-registered and supply information such as breed content, HGP usage and cattle handling and trucking procedures, to the abattoir at the time of slaughter, through the MSA vendor declaration (MLA 2010b).

Various factors can cause the carcass to be downgraded, which can result in the carcass not receiving MSA grading. The carcass is at its highest risk of damage two weeks pre-slaughter and the first few hours post slaughter: even the best carcass can be significantly affected and can become a low-quality, unacceptable product (MLA 2010b). It is essential that cattle are slaughtered the day after dispatch to avoid undue stress on the animals. The pH of the carcass is critical to the quality and hence the grading of the carcass. The pH of the carcass should not exceed 5.71, as a pH above this level increases the incidence of dark-cutting, which reduces the meat quality. The dark-cutting characteristic is caused by a muscle glycogen deficiency at slaughter (McVeigh and Tarrant 1982). If the muscle pH remains at high levels in the carcass, mitochondrial respiration also remains high, myoglobin is deoxygenated and dark red coloured meat results (Ashmore *et al.* 1973). Animals with dark-cutting meat tend to be more stressed before slaughter, but the problem can also be attributed to the chilling process and the animal's age (older animals have darker-cutting meat) (MLA 2010b). Carcass fat depth, marbling and ossification levels also need to be met (refer to MLA 2010b for detailed information on carcass grading). If a carcass fails to meet the MSA standards it is given a grade code that indicates the specifications that have not been met; it is ineligible to be an MSA-graded carcass, but is still acceptable for other markets (MLA 2010b).

FEEDLOT MANAGEMENT

Feedlotting process

Generally, feedlot cattle spend the majority of their lives on pasture and come to a feedlot only to be finished for a specific market. Some cattle enter the feedlot straight from a grazing property on consignment or are purchased by the feedlot, or they may have been purchased from a saleyard. Cattle may be backgrounded by being given access to grain, vaccinated and co-mingled before entry into a feedlot. This reduces post induction problems within the feedlot and improves cattle health. Drought-affected cattle may also enter feedlots, and this can include cull cows.

Cattle generally travel to a feedlot by truck. While it is ideal that the distance travelled is as short as possible, it is not uncommon for cattle to travel up to 48 hours.

Upon arrival, cattle are unloaded and inspected for injury, their health status is assessed and they are allowed to settle for a period (a few hours to a few days) before being inducted. During the induction process, particular details of each animal are recorded, including date arrived/inducted, breed, age, weight, and any other significant features of the animal (e.g. physical features). Health treatments are given to remove internal and external parasites and animals are vaccinated against bacterial and viral diseases. These treatments vary depending on the feedlot's health protocols and the animal's background. The cattle are given an identification eartag for ease of identification within the feedlot and in some cases are implanted with hormonal growth promotants (HGPs). However, with a ban on HGP use imposed by a major retailer in Australia in 2011, HGP use within feedlots has reduced.

When the induction procedure is completed the cattle are placed into pens according to breed, weight or target market. The grouping of animals simplifies the feeding procedure and the final turnoff of the finished animals. The number of animals allocated to a pen depends on the desired stocking density (normally an area 12–17 m^2/animal is provided), trough space and watering facilities. Feedlot design is discussed below.

As the cattle reach market weight they are transported from the feedlot to a processing plant. Transport is usually by cattle truck and is as short a distance as possible with welfare protocols upheld. The choice of processing plant depends on various factors including target market, price and location. After processing, the meat products are sent to market (Chapter 2).

Feedlot design

Site selection and feedlot design are critical factors for successful feedlotting. There are many factors to be considered when selecting a site for the feedlot so the environmental, economic and animal welfare aspects of the feedlot ensure its long-term viability, security and sustainability (Skerman 2000). There are various design principles that should be followed, including stocking density, pen slope, pen size, feed and water trough allocation, apron size, pen orientation, fences, lanes and gates, shade and drainage.

The Queensland government highlighted the importance of capturing all runoff from feedlot surfaces (i.e. the controlled drainage area which flows into sedimentation and holding ponds). When designing new feedlots or expanding existing feedlots, the following information is required:

- number of production pens;
- number of hospital pens;
- total pen area;
- total hard catchment area, e.g. roads, drains, cattle lanes, manure stockpile, sedimentation system, holding ponds;
- total soft catchment area, i.e. those areas permanently grassed or vegetated;
- pen slope, including the downslope and cross-slope;
- drainage slope.

Sedimentation system and holding pond information is also required:

- type;
- drain length, i.e. longest drain in the feedlot;
- volume.

Stocking density

Stocking density is the average feedlot pen area allocated to each animal (DAFF Qld 2012c). The minimum stocking density for feedlot cattle in a pen is 9 m^2/head with a maximum of 25 m^2/head (Primary Industries Standing Committee 2004). Climate and animal size should also be considered when selecting an appropriate stocking density (DAFF Qld 2012c).

Drainage

Feedlot pen surfaces have a slope of 3–6%, with 3% being the most common. This allows sufficient drainage to permit the pens to dry out rapidly after rainfall. The drainage system should be enough to prevent pens becoming excessively boggy. The slope of the pen is from the feedbunk area towards the rear of the pen (DAFF Qld 2012c). Drains are located outside pens. The drain bed should be a minimum width of 3 m to allow for ease of maintenance. The bed gradient of drains below the pen should be 0.5–75% (DAFF Qld 2012c).

Pen size ranges from 50 to 250 head. Pen depth is usually restricted to a maximum of 65 m, which minimises the distance from the rear of the pen to the feedbunk at the front of the pen. Pen width (50–80 m) allows for ease of cleaning with machinery. Feedlot pens are generally orientated with a northerly aspect, which allows maximum exposure to the winter sun and shelter against possible southerly winds.

Feed trough and water trough requirements

Generally there needs to be 30 mm of water trough space per head (Skerman 2000). Feed troughs need to adhere to the same guidelines and allow all animals to eat with minimal competition. A minimum of 150 mm/head for young cattle and 180 mm/head for steers and bullocks is desirable (Primary Industries Standing Committee 2004) (Fig. 11.3). Aprons from the feedbunk (on the inside of a pen) are constructed of reinforced concrete with a depth of 125 mm. The aprons are 2.5–3 m wide and have a 2–3% slope away from the feedbunk (DAFF Qld 2012c).

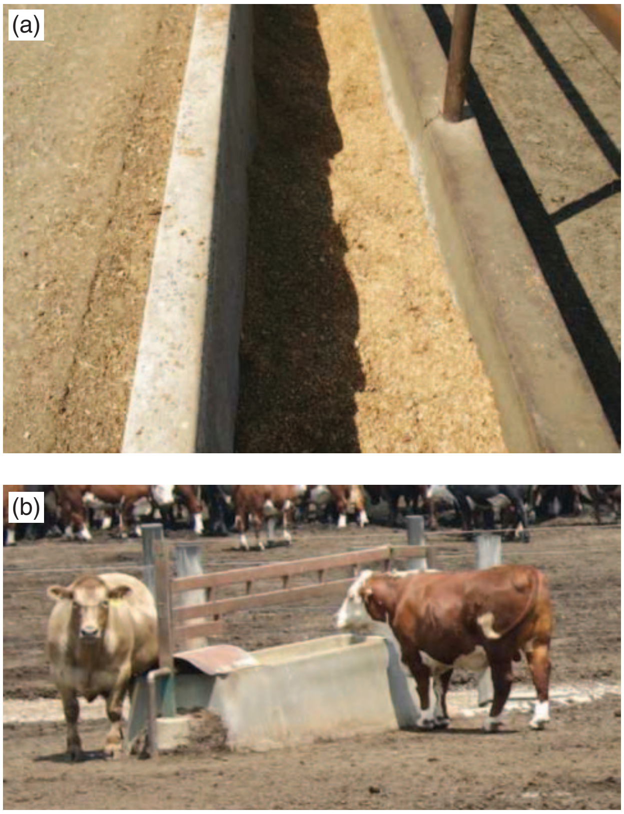


Figure 11.3: (a) Typical feed trough. (b) Water trough. Photos: J.B. Gaughan.

Fences and laneways

Fences, laneways and gates within the feedlot are designed to allow effective movement of cattle, feed trucks and machinery (Skerman 2000). The distance between pens and cattle handling areas is minimised, to prevent unnecessary stress on cattle. Lanes usually have a width of 4–5 m and if lanes are to be used by trucks a width of 6–7 m is common; however, there is considerable variation (Fig. 11.4). Gates should be located to allow ease of access to pens by horse riders and have a width of 3–3.6 m. Gates on pens are generally located at the rear of the pen (DAFF Qld 2012c). Fences in a feedlot are mostly constructed with steel posts and wire cables and are generally 1.4 m high, unless excitable cattle are to be held in which case they will be higher. The bottom

Figure 11.4: Feedlot pen constructed from (a) steel pipe and (b) with a wide lane for vehicular traffic. Photos: J.B. Gaughan.

cables are normally 200–400 mm above the surface of the yard to allow for cleaning (Skerman 2000; DAFF Qld 2012c).

Shade

Heat load can be alleviated through pen modifications such as shade, pen aspect and feedlot location. Shade is a common feature in Australian feedlots and, although not compulsory, in 2012 there were calls from groups such as the RSPCA for shade to become mandatory. About 80% of Australian feedlots have some shade, and many of these would have shade available in most pens. Shade is an efficient way of dissipating heat and regulating body temperature (Bennett *et al.* 1985) to provide immediate relief from the direct effects of solar radiation and diffuse reflected radiation (Buffington *et al.* 1983). It has been shown to improve levels of production in feedlot cattle during heatwaves and over the course of a hot summer (Gaughan *et al.* 2010; Sullivan *et al.* 2011). Gaughan *et al.* (2010) reported an increase in hot carcass weight for Angus steers which had access to shade (321 kg) compared with un-shaded steers (315 kg). During periods of high heat load, steers with access to shade had lower maximum body temperature (Fig. 11.5).

There are many factors to be considered when erecting shade, including orientation, space, height and roof construction (Buffington *et al.* 1983). The best orientation in Australia is north–south as this allows the shade to move across the pen during the day, and helps to dry out the area under the shade. The shade height is normally 3–4 m (some are higher) as the higher the shade the better the air movement under the shade, and the movement of shade is greater (more of the pen is shaded) as the sun moves east to west. It is also important that pen cleaning machinery be able to access the area under the shade structure without damaging the shade material or the shade supports. In most feedlots, shade structures are located approximately two-thirds the depth of the pen (from the feedbunk). There should be minimal trees, buildings or obstructions within 15 m of a shade structure, as these may inhibit natural air flow (Dalquist 1993).

Many different shade materials are used, ranging from low-quality shade cloth to iron roofing panels and tent-like structures (Fig. 11.6). The material chosen depends on owner preference, cost, required wind loading and shade area required.

Area of shade required

The area (m^2/animal) of shade required for optimum effect has not been fully established. The area of shade offered to cattle (midday footprint) in Australian feedlots typically ranges from 2–3.5 m^2/animal; most provide a target shade area of 2.5 m^2/animal. Sullivan *et al.* (2011) investigated the effect of various shade areas on welfare and performance of feedlot cattle. Varying shade sizes (2 m^2, 3.3 m^2 and 4.7 m^2/animal) provided by 70% solar block, black shade cloth at a height of 4 m were used to investigate the influence of shade size on short-fed feedlot cattle (Angus yearling heifers) during summer. Shade size influenced shade usage and increasing heat load was the primary driver for shade usage (Fig. 11.7). Heat load was assessed using the heat load index (HLI) (Gaughan *et al.* 2008). The HLI is a climate-based index which uses ambient temperature, solar radiation, relative humidity and wind speed to assess the impact of environmental heat load on animals. For the purposes of the study the HLI was categorised as cool (HLI <70.0), moderate (HLI 70.1–77.0), hot (HLI 77.1–86.0) and very hot (HLI >86.0). HLI is further explained below.

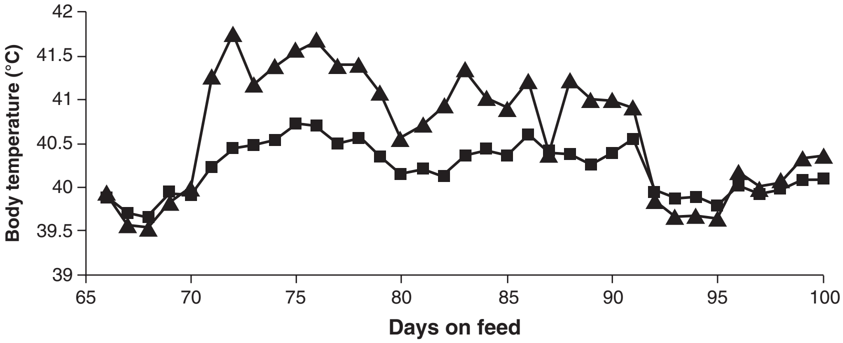


Figure 11.5: Maximum body temperature of feedlot steers with (■) and without (▲) access to shade over a 45-day period which includes a 21-day period (days 71–91) of high heat load. Source: Gaughan *et al.* (2010).

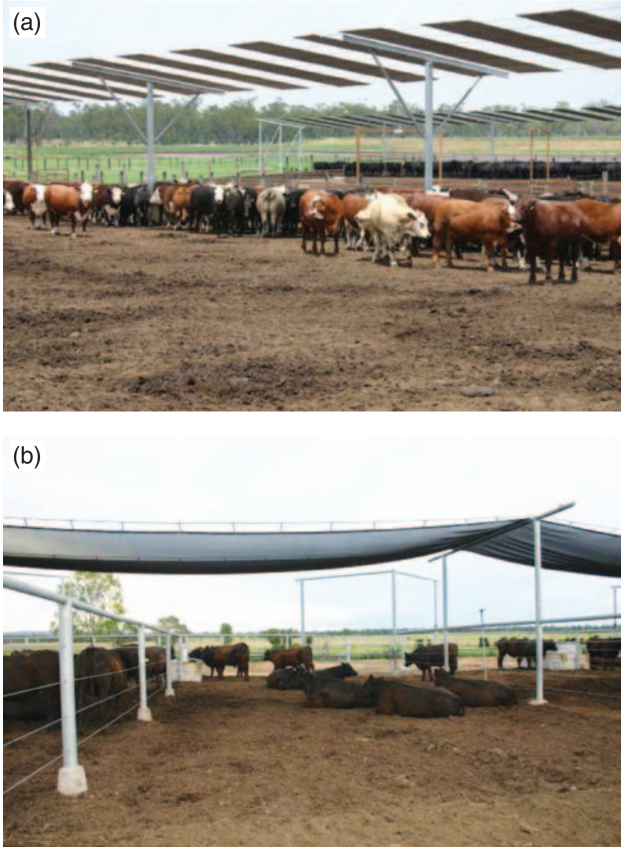


Figure 11.6: Different shade structures in Australian feedlots. (a) Steel panels with gaps to allow air flow. (b) 90% solar block shade cloth. Photos: J.B. Gaughan.

Feedlot layout

Feedlot designs in terms of pen layout, number of pens and placement of additional infrastructure are variable and are somewhat site-specific. The two designs shown in Fig. 11.8 are examples of layouts recommended by the DAFF (Qld) for small and larger carrying capacity feedlots.

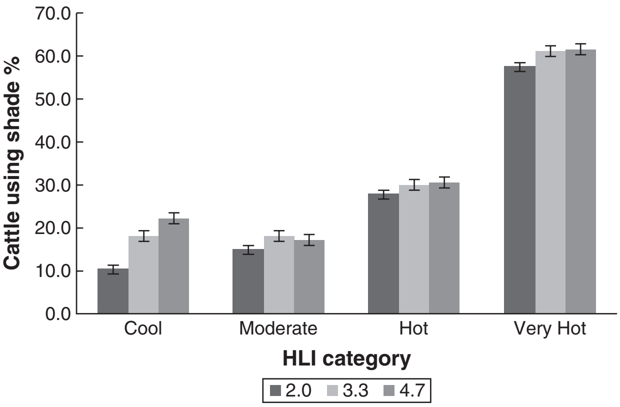


Figure 11.7: Variation in shade usage with increasing heat load using three shade sizes (m^2/animals). Source: Sullivan (2011).

Breed selection

Australian feedlots utilise various breeds, with Angus the most common. Other breeds include Hereford, Charolais, Wagyu, Brahman and various crossbreds. The particular breed in a feedlot/feedlot pen is dependent on various factors including location (e.g. central Queensland *v.* Victoria), target market(s) and breed preference. Many feedlots supply to specific markets and therefore will mainly use the breed preferred by that market (e.g. 120-day feeder steer market prefers British breeds).

Climate has a significant role in breed selection. In central Queensland, for example, Brahman and Brahman cross cattle are commonly used in feedlots due to their better heat tolerance (they are also the dominant breed in the area) whereas in Victoria, Angus and Hereford cattle dominate feedlots.

Feeding regime and ration formulation

Grain fluctuates in price and availability, and because of this feedlot rations tend to be flexible. The ration needs to contain ingredients that meet the nutrient requirements of the animal, at the lowest cost (Forster 2012). The ration is formulated to optimise weight gain and fat deposition in order to meet the target market specifications. Up to 85% of the energy content of the ration is generally supplied through cereal grains (MLA 2012d). Feedlot operators try to keep input costs (feed) at a minimum, but simultaneously optimise performance and feed conversion efficiency.

Feedlot cattle are gradually introduced to a grain-based ration over the first 15–20 days at the feedlot. This allows the rumen microflora to adjust to the diet change gradually and minimises the risk of an adverse response, such as acidosis (Chapter 13). Grain/roughage diets are commonly fed at 75:25 or 80:20, which will give adequate weight gain with minimal risk of adverse effects, and are usually fed at a rate of 2.5–3% of liveweight (MLA 2012d; Government of NSW 2004).

The common grain types used in Australian feedlots are sorghum, maize, wheat and barley (Chapter 16). Sorghum is commonly used in feedlots, but it has a lower metabolisable energy (ME) and crude protein content than other grains. Sorghum is a highly suitable grain to feed if targeting the Japanese market, as it produces pearly white fat with an ideal texture (Sneath and Bath 2012). Maize has a higher ME than most grains but tends

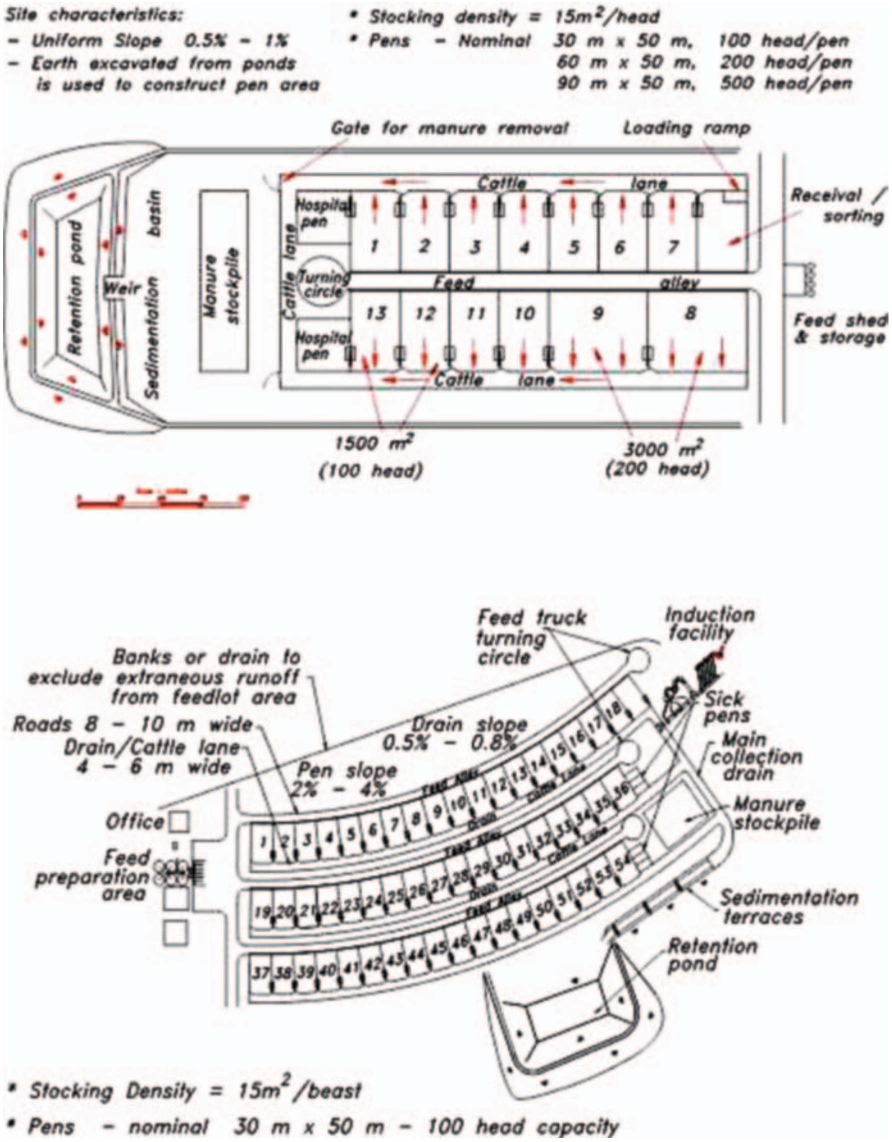


Figure 11.8: Two recommended feedlot layouts. Source: DAFF Qld (2012a, b).

to be low in crude protein content. It is not grown as widely in Queensland as are other grains and tends to be expensive when it is available (Sneath and Bath 2012). Wheat has a high ME and crude protein of 7–15%. Wheat is easily fermented in the rumen, which can increase the risk of acidosis, so is generally restricted to no more than 50% of the total grain content. It is best rolled before feeding (Sneath and Bath 2012). Barley is widely used in feedlot rations and in addition to supplying energy and protein it is a fibre source for feedlot cattle. Grains are processed before their inclusion in the diet. The common grain-processing methods used by Australian feedlots are rolling, steam flaking, reconstitution (Sneath and Bath 2012) and occasionally extrusion or pelleting.

The main nutrient components of a feedlot diet which are considered in formulation are ME, crude protein (nitrogen × 6.25), fibre and minerals (Chapter 16). Generally diets are formulated to first meet the targeted energy specification, which for accredited grain-fed beef is a minimum of 10 MJ ME/kg DM. Crude protein (CP) is generally supplied in the range of 11–15% of the diet. In many cases the CP component of feedlot diets is greater than required for optimal growth and surplus urea is excreted in the urine. Excess nitrogen on the pen surface can be volatised to N_2O which is a greenhouse gas. Furthermore, supplying excess protein is expensive.

High-energy diets will lead to maximum weight gain but there is a risk of digestive problems when grain is increased to over 80% of the diet. Various minerals can be included in the feedlot ration, depending on the desired outcome. The most common are calcium, phosphorus, magnesium, sulphur and salt (0.1–0.5%). A wide variety of supplements can be added to feedlot rations, including rumen buffers (e.g. sodium bicarbonate, sodium/calcium bentonite), rumen modifiers/antibiotics (e.g. monensin, tylosin) and other supplements (fats, oils) (MLA 2012d). Vitamin E has been used as a supplement for feedlot cattle to improve the immune response. Supplementing feedlot rations with vitamin E has been shown to improve ADG (1.42 *v.* 1.38 kg/day) and feed:gain (6.41 *v.* 6.53) (Secrist *et al.* 1997). In contrast, Duff and Gaylean (2006) found that addition of vitamin E in the diet decreased morbidity from bovine respiratory disease but had little effect on animal performance.

The feeding of additives to improve ruminal microbial metabolism (Spears 1990) is common. Feed additives are usually in the form of ionophores – compounds that form lipid-soluble complexes with certain cations then facilitate their transport across biological membranes (Spears 1990). Examples of ionophores include monensin, lasalocid, salinomycin and lysocellin (Spears 1990).

Burrin *et al.* (1988) found that feeding 33 mg monensin/kg of feed reduced variation in feed intake. Monensin may also allow the feeding of higher levels of rapidly fermenting grains or lower levels of roughage, as is common in finishing feedlot diets, without resulting in subacute acidosis (Stock *et al.* 1990).

It is illegal to feed any animal by-products (e.g. meat meal) to cattle.

Heat stress and nutrition

Heat stress can be a major issue for feedlot cattle and nutrition can be a factor that contributes to the heat load placed on animals. The metabolic heat generated from the diet can significantly contribute to the heat load and can be related to the specific ingredients in the ration. Feed intake, diet composition and the physiological status of the animal will influence the total amount of heat generated from feeding (Hall 2000). Total heat production is known as the amount of energy transferred from the animal to the environment. It consists of numerous components: fasting metabolism, heat associated with voluntary activity, heat of product formation, heat of thermal regulation, heat of digestion and absorption, heat of waste formation and excretion and heat of fermentation (NRC 1981; Mader *et al.* 1999; Chapter 16).

Different feeds produce different amounts of heat when they are consumed by the animal. The heat increment (HI) is the increase in heat production following the consumption of food (Conrad 1985) and is a non-useful form of energy in hotter climates (Blackshaw and Blackshaw 1994). Fats have the lowest HI, followed by carbohydrates then protein (Conrad 1985). Fibre has a high HI and, in order to reduce the heat production of the feed as a partial protective measure against heat stress (Blackshaw and Blackshaw 1994), fibre levels should be decreased. However, fibre can be used to physically limit the animals' intake and it plays an important role in the minimisation of digestive dysfunction (Beede and Shearer 1991). The inclusion of roughages into a high-grain finishing diet can assist ruminal function though enhancing salivation, rumination activity and the digesta passage rate (Mader *et al.* 1999).

If the level of roughage in the diet is decreased, the resultant heat of fermentation will also be decreased. A higher level of roughage in the diet can lead to a gradual rise in heat production after feeding. This is because the concentrate will be absorbed post-ruminally and it will produce heat at a different time from rumen fermentation (Hall 2000). If the roughage level in the diet is increased the DMI may increase, but as a consequence the gain efficiency can decrease linearly as the roughage content of the diet increases. If the roughage level is tapered off in the mid-finishing period, gain efficiency and carcass characteristics can be improved (Bartle *et al.* 1994).

Supplements can increase the average daily gain of cattle. The addition of fat to a low-forage diet of crossbred steers did not affect the average daily gain, but its addition into a high-forage diet increased gain (Zinn and Plascencia 1996). Supplemental fat increases the energy density of the diet, which decreases the total HI of the ration (Beede and Shearer 1991). Supplemental fat can be substituted in many forms including but not limited to sunflower seed, soybean meal, whole soybeans, yellow grease, tallow, whole cottonseed and safflower oil.

Steers fed supplemental fat in the form of soybean meal, yellow grease and tallow gained weight 8.5%, 12% and 5.6% faster respectively than cattle not fed any fat (Brandt and Anderson 1990). In this study tallow had the highest diet net energy for both maintenance and gain (Table 11.9).

The time of day of feeding can have a substantial influence on the metabolic heat that is produced from a diet (Mader 2003). Ruminal fermentation of a high-grain diet peaks within 12 h of the consumption of the feed, so cattle fed in the morning dissipate their metabolic and climatic heat in the hottest part of the day. If cattle are fed in the evening they are able to dissipate their metabolic and

Table 11.9: Effect of supplemental fat type on diet net energy

Diet net energy (MJ/kg)	Control	SBSS[1]	70 SBSS:30 tallow	Tallow	Yellow grease	Soybean oil
Maintenance	8.74	8.91	9.25	9.25	9.08	0.15
Gain	5.94	6.07	6.40	6.40	6.28	0.13

Source: Brandt and Anderson (1990).
1. SBSS = acidulated soybean soapstock.

climatic heat in the coolest part of the day (Reinhardt and Brandt 1994).

Time of feeding affected the DMI of cattle fed in the afternoon under hot conditions (maximum temperature 39°C) compared with morning feeding and split feeding (Table 11.10). Under both thermoneutral (maximum temperature 31°C) and hot conditions, split fed cattle had the greatest DMI, with the exception of thermoneutral afternoon fed cattle (Gaughan *et al*. 1996). Under hot conditions split fed cattle exhibited a lower rectal temperature (Gaughan *et al*. 1996), indicating that cattle regulate their intake between feedings in order to minimise increases in body temperature.

Ray and Roubicek (1971) found cattle with *ad lib* access to feed had two major peaks of eating activity. The cattle began eating around sunrise and by mid-morning most eating activity had ended. The major period of consumption was in the afternoon and early evening. This indicates that cattle select feeding times that are advantageous to their metabolic and climatic heat dissipation needs.

Growsafe technology

Growsafe (Growsafe Systems Ltd, Calgary, Canada) is a system that has been developed to record feed and water intake and animal behaviour in large groups of cattle in a feedlot. It involves a system of load cells at feedbunks and water troughs that is linked to a radio-frequency identification (RFID) tag on each animal. The system can collect more than 500 000 data points a day on a group of animals at the feedlot (ALFA 2012b).

The system has the ability to:

- continuously and automatically track animals;
- identify sick animals and poor performers;
- visually identify animals needing treatment or market-ready animals;
- measure and predict individual animal liveweight gain and market value (Growsafe 2011).

The software can determine performance outliers and animals that require treatment. It also has the unique ability to define the optimum time to market each animal (i.e. when the cost of gain begins to exceed the value of gain) and can create an optimal truckload from multiple pens. Animals that have been noted as ready for market can be identified using spray paint that is applied by the system at the animal's next visit to the drinking area (Growsafe 2011).

The Growsafe system can also monitor feeding rate through a feeding event, feeding frequency over a particular time span, animals standing at the feedbunk not consuming feed, and numbers consuming feed (Growsafe 2011). Animals with altered feeding and watering behaviour can be identified and treated before the onset of illness (Duff and Gaylean 2006).

The system's ability to measure feed intake, water intake and feed efficiency can lead to an improvement in animal management, diet formulations and understanding of the interaction between management, nutrition, physiology and genetics (Kolath *et al*. 2007; Sherman *et al*. 2009).

Table 11.10: Mean daily dry matter intake and metabolisable energy intake of cattle fed feedlot diets and exposed to thermoneutral or hot environmental conditions

		TNL			HOT	
Feeding time	**am**	**pm**	**sp**	**am**	**pm**	**sp**
DMI (kg/day)	7.32	7.48	7.48	7.17	6.49	7.56
DMI (% BW)	2.62	2.72	2.72	2.60	2.28	2.64
MEI (MJ)	86.69	88.55	88.68	84.61	76.62	89.94
MEI (% BW)	31.07	32.19	32.26	30.67	26.90	31.43

BW = bodyweight; DMI = dry matter intake; MEI = metabolisable energy intake; TNL = thermoneutral; HOT = hot.
14% roughage diet (7% oat hay and 7% lucerne hay); am = fed at 0800 each day; pm = fed at 1600 each day; sp = split feeding regime (1/3 of dietary intake was provided from 30% roughage diet fed at 0800, remaining dietary intake provided from 6% roughage diet fed at 1600).
Source: Gaughan *et al.* (1996).

Economics of feedlotting in Australia

Feedlotting is a capital-intensive industry, characterised by fluctuating returns. In 2012 the cost of establishing a feedlot was approximately AUD$1 million per 1000 cattle. The profitability of a feedlot is a function of cattle prices in and out, feed costs, feed efficiency, cattle losses (mortality and morbidity) and days in the feedlot. Feed accounts for ~70% of the total costs of producing a feedlot animal. However, it is feed efficiency (kg growth per DMI) and ration cost (on a DM basis) that are major drivers of profitability (Chapter 18). As the cost of gain (i.e. cost of feed to obtain 1 kg liveweight gain, derived by multiplying FCE × ration cost) is often higher than the return on that gain, the liveweight and purchase and end sale price of an animal are major factors determining profitability.

Difficulties in predicting grain and cattle prices make feedlotting a difficult business, and this is further compounded by the vagaries of the international market. Domestic cattle, export cattle and grain prices fluctuate widely from year to year, which leads to uncertainty in profitability (Figs 11.9, 11.10). In an effort to gain stability in feed costs and sale costs of cattle, some producers use grain futures and forward cattle contracts to lock in prices (http://www.asx.com.au/products/grain-futures-options-benefits.htm).

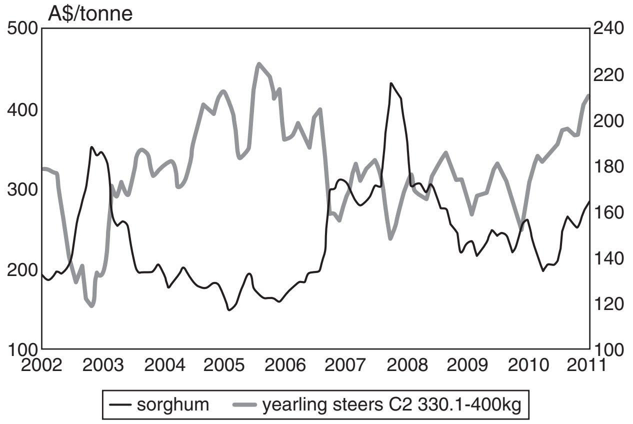


Figure 11.9: Australian feeder cattle and grain sorghum prices, 2002–11. Source: MLA (2012f).

Importance of feed efficiency

Using the same input costs, the return on investment (ROI) effects of two feed conversion ratios (FCR) are shown in Table 11.11. In this example neither option is profitable (not an uncommon occurrence in 2012), however, the group with an FCR of 5:1 had a loss of only $22.88/animal while the group with an FCR of 7:1 had a loss of $102.96/animal. Improving the FCR to 4.4:1 would give a small profit ($1/animal) with the assumed costs, a 4:1 FCR would result in $17.12/head profit and a 7.35% ROI. However, improving FCR below 5:1 is very difficult.

ISSUES FACING THE FEEDLOT INDUSTRY

Issues facing the Australian feedlot industry include use of hormone growth promotants, animal welfare and ethics, heat stress, animal health, weather, feed security and environmental concerns.

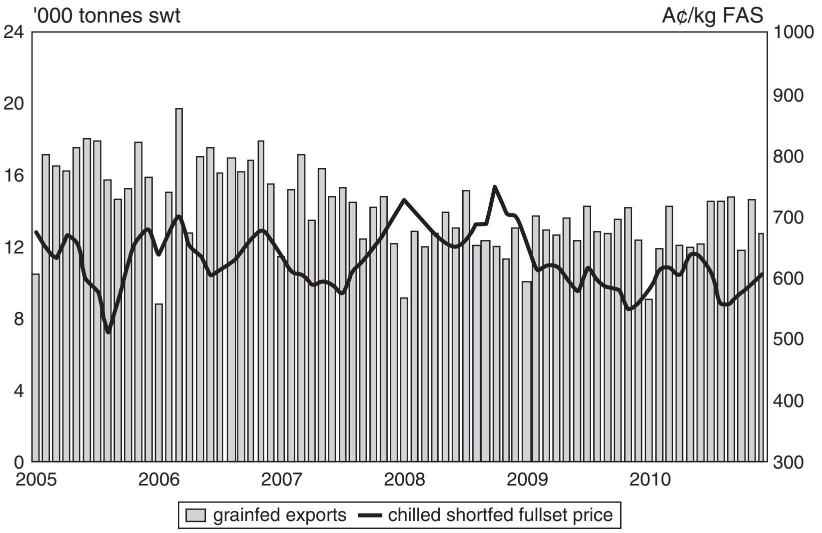


Figure 11.10: Australian grain-fed cattle exports (t) and prices (c/kg) to Japan. Source: MLA (2012f). swt = standard weight.

Table 11.11: Impact of feed efficiency on feedlot profitability

Beef feedlot costs and returns 20 December 2012				
Input factors			**Option 1**	**Option 2**
No. of animals in feedlot group			200	200
Average purchase weight (kg)			320	320
Purchase price ($/kg LW)			1.90	1.90
Purchase price ($/hd LW)			608	608
Total purchase			121 600	121 600
Expected daily weight gain (kg)			1.6	1.6
Days in feedlot			100	100
Expected sale weight LW (kg)			480	480
Expected weight gain (kg)			160	160
Expected carcass weight (kg)			264	264
Expected LW	Option 1	Option 2	422.40	422.40
Feed to gain input est.	5	7	800	1120
Feed required (kg/hd)			800	1120
Stock loss (%)			0.10	0.10
Annual interest rate (%)			0.00	0.00
Commission rate (%)			0.00	0.00
Average cost of feed ($/t)(includes mixing)			250	250
Costs (head)				
Feed			200	280
Freight in			22	22
Freight out			13	13
Labour			8	8
Interest on stock value			0	0
Interest on feed value			0	0
Commission (on sale of stock)			0	0
Levy			5	5
Miscellaneous			0	0
Structures			9	9
Health			2	2
Induction (tags, vaccinations, etc.)			13	13
Cost of stock losses			0.88	0.96
Total cost (hd)			272.88	352.96
Total cost/kg of weight gain			1.71	2.21
Feed cost/kg of weight gain			1.25	1.75
Sale price ($/kg CWT)			3.25	3.25
Sale price ($/hd CWT)			858	858
Profit margin ($/hd)			–22.88	–102.96
Break-even sale price ($/kg live)			1.84	2
Break-even sale price ($/kg carcass)			3.25	3.25
Break-even purchase price ($/kg)			1.83	1.58
Value of grain by feedlotting ($/t)			227.12	147.04
Max. price payable for grain ($/t)			221.40	158.07
Total expected costs ($)			54 576.18	70 592.19
Total expected income/loss ($)			–4576.18	–20 592.19
Expected return on investments (%)			–8.38	–29.17

Hormone growth promotants

'Hormone growth promotants (HGPs) are supplements of naturally occurring hormones (female hormones, i.e. oestradiol and progesterone, and male hormones, i.e. testosterone and trenbalone acetate) that are found in most plant and animal life. They are slow-release implants that contain natural or synthetic hormones used to improve growth rates and feed efficiency in the cattle industry' (MLA 2010a). HGPs allow beef to be produced more efficiently, as shown through improved feed:gain and feed efficiency (Hunter 2010); however, implants may negatively influence beef palatability (Watson 2008). HGPs may affect the eating quality of some cuts of meat, with the striploin and cube roll the most affected, rump and topside mildly affected and the other cuts less affected, as based on MSA research (MLA 2010b). Ossification has been shown to be affected with HGP implantation, with an increase in this as days between initial implant and slaughter increase (Polkinghorne *et al*. 2008). HGPs have been shown to increase liveweight gain by 18–25%, feed intake by 6% and FCR by 8% (Hunter 2010; Hoffman and Hearnshaw 1996). Improvements in FCR are critical to feedlots as feed costs are the largest variable cost (Hunter 2010).

The EU banned the use of HGPs in 1988, although the decision was not supported by international opinion and leading world health authorities. The USA challenged the ban in 1989 and started World Trade Organization (WTO) litigation against the EU. In 1998, the WTO found that the EU's ban was not supported by science (Cattle Council of Australia 2008). The actual level of hormones found in beef cattle dosed with HGP is less than that found in common foods such as soybean oil, cabbage and eggs. One egg contains the same level of oestrogen as 77 kg of beef treated with HGPs (MLA 2010a).

The supply of beef products to the EU faces strict regulations in regard to HGP usage; as such, the cattle should not be treated with HGPs. To be eligible for this market, cattle must be obtained from a supply chain accredited by the EU Cattle Accreditation Scheme (EUCAS), which includes producers, feedlots and saleyards. Properties need to be inspected before accreditation under this scheme. It has stringent regulations and feedlots must have approved management plans to ensure EUCAS cattle are segregated at all times (MLA 2011).

The Coles supermarket chain in Australia announced in 2010 that it would source HGP-free beef from its Australian producers (Coles 2010). The reason was said to be widespread consumer concern over additives in food and livestock and animal welfare practices. The move was a statement about striving to provide quality fresh food, although there is little evidence to support the link between HGP usage and the freshness of meat products.

Animal welfare and ethics

Animal welfare is paramount in the feedlot industry, which has implemented several animal welfare initiatives. The industry is aware of its social and ethical responsibility to consumers and society as a whole and continues to improve standards (ALFA 2006).

The legislative responsibility for animal welfare is entrusted to state governments (Chapter 13). Each state has comprehensive animal welfare legislation that is specifically designed to prevent animal cruelty. The National Consultative Committee on Animal Welfare (NCCAW) Position Statement has guidelines that must be followed to maintain the welfare of the animals within the feedlot. Some feedlot staff are specifically trained to implement the welfare guidelines and ensure the health and welfare of cattle.

If the appropriate procedures are not followed, heat stress and health issues can occur. In 2012 the RSPCA issued a statement that shade must be provided for all feedlot cattle (ALFA 2012a).

Heat stress

Excessive heat load or heat stress can result from a combination of environmental heat and metabolic heat production that results in a level of animal discomfort (Mader *et al*. 1999). Heat stress is a major issue in the Australian feedlot industry due to the climatic conditions – high temperatures, solar load and humidity in summer months. Common heat stress responses include:

- reduced feed intake;
- suboptimal performance;
- decreased activity;
- shade- or wind-seeking;
- increased respiratory rate;
- increased peripheral blood flow and sweating (Shearer and Beede 1990).

Several animal factors may also increase the likelihood of an animal becoming heat stressed. These factors include:

- genotype;
- coat colour and type;
- days on feed;
- body condition and health status;
- adaptation and acclimatisation.

Heat stress usually affects production, productivity and efficiency. It is now an NFAS requirement that feedlots have a heat stress management plan that outlines the steps taken to minimise the impact of heat load. These plans generally involve providing shade and increased water availability and the feeding of a heat load ration (usually higher fibre content). A web-based management tool (Katestone 2012) was developed in 2006 to assists producers in predicting the weather conditions, allowing them to be prepared for impending excessive heat load events. Feedlotters can use the website to predict their overall risk of heat load (based on historical weather data) (Table 11.12, Fig. 11.11).

Heat assessment indices

Heat load index

The HLI was developed to assist in understanding the relative significance of the climatic variables and how they affect animals (Gaughan *et al*. 2008). It was developed as a guide to the management of *Bos taurus* feedlot cattle in hot conditions. The index is based on relative humidity (RH, %), wind speed (WS, m/s) and black globe temperature (BGT, °C) (Gaughan *et al*. 2008).

The index takes the following form.

For black globe temperatures >25°C:

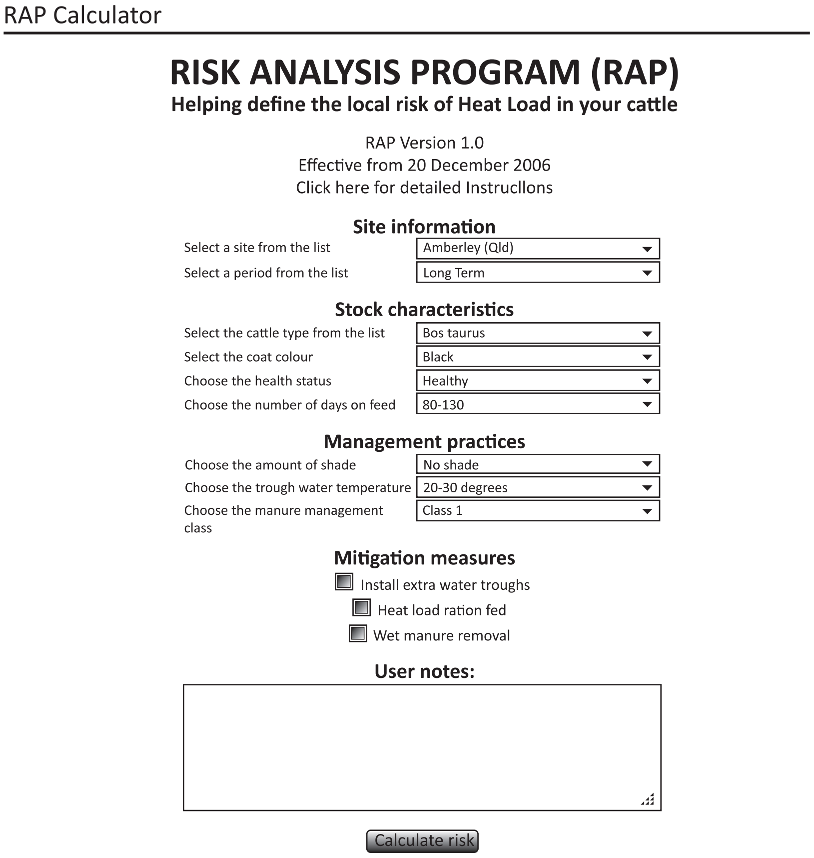
$$\text{HLI} = 8.62 + (0.38 \times \text{RH}) + (1.55 \times \text{BGT}) - (0.5 \times \text{WS}) + [e^{2.4\text{-WS}}]$$

where e = the base of the natural logarithm (~2.71828).

For black globe temperatures <25°C:

$$\text{HLI} = 10.66 + (0.28 \times \text{RH}) + (1.3 \times \text{BGT}) - \text{WS}$$

The thresholds for various classes of feedlot cattle based on field and laboratory observations in Australia are presented in Table 11.13. These thresholds allow the HLI to be adapted for various locations and across locations within a property. This allows comparisons between conditions and animal response without having to consider the thresholds and factors, as they are already accounted for in the HLI. The HLI value is altered (increased or decreased) according to the animal and management practices. A higher value suggests a greater



RAP Calculator

RISK ANALYSIS PROGRAM (RAP)

Helping define the local risk of Heat Load in your cattle

RAP Version 1.0
Effective from 20 December 2006
Click here for detailed Instrucllons

Site information

Select a site from the list	Amberley (Qld)
Select a period from the list	Long Term

Stock characteristics

Select the cattle type from the list	Bos taurus
Select the coat colour	Black
Choose the health status	Healthy
Choose the number of days on feed	80-130

Management practices

Choose the amount of shade	No shade
Choose the trough water temperature	20-30 degrees
Choose the manure management class	Class 1

Mitigation measures

☐ Install extra water troughs
☐ Heat load ration fed
☐ Wet manure removal

User notes:

Figure 11.11: Screenshot of the Risk Analysis Program. Source: Katestone (2012).

Table 11.12: Risk assessment inputs and output showing the risk of high heat load events

Parameter	Value	
Site	Amberley (Qld)	
Period analysed	Long-term	
Cattle type	*Bos taurus*	
Coat colour	Black	
Health status	Healthy	
Number of days on feed	80–130	
Amount of shade	No shade	
Trough water temperature	20–30°C	
Pen class	Class 1	
Extra water troughs installed	No	
Heat load ration fed	No	
Wet manure removal	No	
HLI value that stock begin to accumulate heat stress: 86		
Event duration	**High-event frequency**	**Extreme-event frequency**
2 days	1–2 events/year	1–2 events in 2 years
3 days	1–2 events in 2 years	1–2 events in 4 years
4 days	1–2 events in 2 years	1–2 events in 4 years
5 days	1–2 events in 3 years	1–2 events in 10 years
6 days	1–2 events in 4 years	1–2 events in 10 years
7+ days	1–2 events in 2 years	1–2 events in 4 years

Source: Katestone (2012).

tolerance to hot conditions; a lower value suggests greater susceptibility to conditions – consequently this animal will gain heat (accumulated heat load units) at a lower HLI.

Accumulated heat load units

Accumulated heat load units (AHLU) are an indicator which provides information on whether cattle have had sufficient night cooling to adequately recover from the previous day' s heat load. If the cattle have had an insufficient amount of recovery time they tend to have higher panting scores and a reduction in feed intake the next day, even if heat load has decreased (Gaughan and Goopy 2002). The AHLU are determined by the duration of the exposure to heat load over the threshold HLI for an animal and its conditions (Gaughan *et al*. 2008). The accumulated HLI-hours allow the HLI to be progressively recorded as an accumulated total over consecutive days and to incorporate local weather forecasts (Gaughan and Goopy 2002).

The AHLU indicator was developed in an attempt to include the intensity of exposure and the duration of that exposure to extreme heat. It was developed using the concept of THI hours (Hahn and Mader 1997), which is a two-dimensional function incorporating time and heat balance, calculated by determining the difference between the HLI at a given time and an upper and lower threshold HLI (Byrne *et al*. 2005). This indicator is extremely useful for feedlot operators, as it allows them to assess the cattle's accumulation of heat and to adjust diets and other managerial processes accordingly.

In order to calculate AHLU a reference animal (healthy, unshaded Angus, 100 days on feed) is used. For the reference animal the upper threshold at which the animal 'accumulates' heat was established at HLI = 86 and the lower threshold at 77. For a Brahman *(Bos indicus)* the upper threshold was defined as HLI = 96. Over a 24-h period the AHLU may be increasing or decreasing. The AHLU value will never fall below 0, as a 0 value indicates that the animal is in thermal balance.

The following equation (Gaughan *et al*. 2008) calculates the AHLU:

$$\text{If } (\mathrm{HLI}_{\mathrm{ACC}} < \mathrm{HLI}_{\text{Lower threshold})} \text{ then}$$
$$\mathrm{AHLU} = (\mathrm{HLI}_{\mathrm{ACC}} - \mathrm{HLI}_{\text{Lower threshold}})/M$$
$$\text{If } (\mathrm{HLI}_{\mathrm{ACC}} > \mathrm{HLI}_{\text{Upper threshold})} \text{ then}$$
$$\mathrm{AHLU}\ (\mathrm{HLI}_{\mathrm{ACC}} - \mathrm{HLI}_{\text{Upper threshold}})/M)$$

otherwise AHLU = 0.

Table 11.13: Animal (genotype, coat colour, health status, acclimatisation) and management (access to shade, days on feed, manure management, drinking water temperature) adjustments (+ and -) to the HLI threshold (86) of the reference steer (healthy unshaded Angus, 100 days on feed)

Item	Relative effect on upper HLI threshold of a reference steer (HLI = 86)
Genotype[1]	
Bos taurus (British)	0[2]
Bos taurus (European)	+3 (i.e. 86 + 3)
Wagyu	**+4**
Bos indicus (25%)	+4
Bos indicus (50%)	+7
Bos indicus (75%)	+8
Bos indicus (100%)	+10
Coat colour[1]	
Black	0
Red	+1
White	+3
Health status	
Healthy	0
Sick/recovering	–5
Acclimatisation	
Acclimated	0
Not acclimated	–5
Shade[3]	
No shade	0
Shade (>1.5–2 m^2/animal)	+3
Shade (>2–3 m^2/animal)	+5
Shade (>3 m^2/animal)	+7
Days on feed[4]	
0–80	+2
80–130	0
130+	–3
Manure management[5]	
Max. depth of manure pack = 50 mm	0
Max. depth of manure pack = 100 mm	–4
Max. depth of manure pack = 200 mm	–8
Drinking water temperature[6]	
15–20°C	+1
21–30°C	0
31–35°C	–1
>35°C	–2

[1] Not all cattle have been assessed within each threshold trait. For example, coat colour was assessed only in *Bos taurus* cattle, manure management at five feedlots and drinking water temperature was assessed on three feedlots.

[2] The values for the reference steer are presented as 0, i.e. no change from the threshold of 86.

[3] For shade that provides 70% blockout (includes shade cloth and steel structures with gaps in the roof). Unshaded *Bos indicus* cattle >25% not included.

[4] Not all cattle were assessed for this trait. Wagyu cattle excluded from 130 + d.

[5] Mean depth over 54 days.

[6] Only unshaded Angus cattle were assessed for this trait.

Source: Gaughan *et al.* (2008).

Where HLI_{ACC} = the actual HLI value at a point in time:

$HLI_{Lower\ threshold}$ = the HLI threshold below which cattle in a particular class will dissipate heat, e.g. 77 for the reference animal.

$HLI_{Upper\ Threshold}$ = the HLI threshold above which cattle in a particular class will gain heat, e.g. 86 for the reference animal.

M = measures per hour, i.e. how often HLI data is collected per hour. If every 10 min then M = 6.

The upper and lower thresholds were developed from climate room and commercial feedlot studies. When the HLI is above the upper threshold (>86), cattle will not be able to effectively dissipate body heat, which means that there is likely to be an increase in core body temperature. When the HLI is below the lower threshold (<77) then cattle are likely to dissipate body heat back to the environment. There is a transition zone when the HLI is between 77.1 and 85.9, where the animal may be either gaining or losing heat (Byrne *et al*. 2005).

Health issues

Health issues within feedlot cattle can be a welfare concern, particularly if not treated. The health of feedlot cattle can be compromised by the intensity of housing, environmental conditions and feeding regimes (Brown-Brandl *et al*. 2003). Any animal with a health problem will have a reduced ability to handle heat stress (MLA 2006) and poor feed conversion efficiency. If an animal is febrile and is exposed to elevated ambient temperatures the combined result could be fatal (Silanikove 2000; Streeter *et al*. 2000). Cattle that have been exposed to overcrowded pens, recent transportation or handling, disruption of their social order and/or inadequate access to feed or water troughs can have health stress problems (Gaughan 2002).

Respiratory diseases are common among feedlot cattle and are generally one of the commonest causes of morbidity and mortality (Gardener *et al*. 1999; Gaughan 2002; MLA 2006; Chapter 13). Bovine respiratory disease (BRD) is a disease complex caused by viral (infectious bovine rhinotracheitis, bovine viral diarrhoea (pestivirus), bovine respiratory syncytial and parainfluenza type 3), bacterial (*Mannheimia haemolytica*, *Pasteurella multocida*, *Haemophilus somnus*) and mycoplasmal organisms (Ellis 2001). There are several predisposing risk factors that can affect the transmission of disease, including environment (climate, temperature, dust, stocking density, humidity), age, stress and immunological background (Snowder *et al*. 2007). BRD has been shown to account for ~75% of feedlot morbidity and 50% of mortality (Edwards 1996). Animals that have the disease may exhibit symptoms such as depression, lack of fill, slow moving and nasal or ocular discharge and a soft cough (Gardener *et al*. 1999). Other symptoms of BRD include rapid breathing and dehydration (Snowder *et al*. 2007). Infected animals are highly susceptible to heat stress. Animals with a rectal temperature >39.7°C are considered morbid and require treatment (Duff and Gaylean 2006).

Another health issue is bovine viral diarrhoea virus, also known as bovine pestivirus (Chapter 13). This can affect feedlot cattle by increasing morbidity and mortality rates and reducing feed consumption and average daily gain. Cattle become infected with the condition through saliva, mucus, faeces or urine contact. The virus is highly contagious and usually causes only transient symptoms but, once infected, the virus causes suppression of the animal's immune system. The animal is then susceptible to secondary infections including BRD, mastitis, pneumonia, footrot, diarrhoea and bovine papular stomatitis (Loneragan *et al*. 2005; Pfizer Animal Health 2007; Smith Thomas 2009).

Climate change

Specific information in regard to climate change is covered below. Climate change is having an impact across many industries. Australia and the globe are experiencing climate change; in the 60 years since the middle of the 20th century, Australia's temperature has, on average, risen by ~1°C, with an increase in heatwaves and the number of very hot days (>35°C) (Sullivan 2011). Climate change will affect the Australian feedlot industry through a possible increase in heat-related issues, feed management and water availability.

Feed management

ALFA states that fodder and feed costs can be up to 60% of feedlot input costs (grain is 75% of this cost) so the price and supply of feed is a serious issue (Commonwealth of Australia 2007). Feedlot cattle consume 2.6–2.8% of their bodyweight daily in feed and will generally gain 1.2–1.5 kg liveweight each day (DPI Vic 2011). The time period required for cattle to reach market weight is dependent on the target market but will generally be a minimum of 60 days, depending on the initial condition of the cattle (DPI Vic 2011).

Feedlot cattle can be fed in various ways, including premixed commercial rations or rations developed and mixed at the feedlot. Various grain types include barley, wheat, triticale, sorghum, maize, lupins and oats in various mixes. Hay or silage is an adequate roughage source. To achieve satisfactory growth rates, a crude protein level of 11–15% is required, depending on the age and weight of the cattle (Government of NSW 2004).

The availability of grain and roughage sources affect the ration fed. The price of grain is subject to significant change and can depend on climatic conditions (drought/flood), not only in Australia but overseas. The 2012 drought in the USA noticeably increased the price of grain in Australia (Swan 2012). Feedlots alter their rations in order to minimise the impact of grain price fluctuations and will include more cost-effective ingredients where possible (George 2012).

The inclusion of roughage in a feedlot diet has been shown to help to prevent digestive upsets and maximise energy intake (Gaylean and Defoor 2003). As a result, cost-effective types of roughage are included in feedlot diets. The inclusion of by-products as alternative roughage sources is common and can include products such as corn and wheat distillers grains, corn gluten feed, soybean hulls, cottonseed hulls and low-quality by-products of the agro-industry such as rice hulls and wood chips (Gaylean and Defoor 2003; Beretta *et al*. 2010; Yang *et al*. 2012). Cattle fed rice hulls (85% neutral detergent fibre) displayed a higher carcass yield ($P < 0.05$) (55%) compared with cattle fed grass hay (66% neutral detergent fibre) (53.5%), indicating that alternative sources of roughage, such as rice hulls, do not inhibit performance (Beretta *et al*. 2010), but this may be dependent on inclusion rates. It has also been suggested that fat contained within wet distillers grains plus solubles (WDGS) may be partially protected from complete biohydrogenation, which then allows an increased flow of unsaturated fatty acids to the duodenum. This allows the fat to be more efficiently utilised by the animal (Vander Pol *et al*. 2009). Average daily gain, DMI and gain:feed were improved when WDGS was fed at 10%, 20% and 30% of the diet when finishing yearling steers compared with a control diet of 0% WDGS (Klopfenstein *et al*. 2008).

Environmental issues surrounding feedlots

The NFAS ensures that all feedlots (as defined at the start of the chapter) are audited annually to ensure compliance with NFAS standards. The feedlot industry is regulated on a state by state basis. Environmental legislation sets management and licensing requirements to prevent or minimise environmental harm in regard to water, air and noise pollution. The waste legislation is a framework for waste prevention, recycling and energy recovery and waste disposal. The planning legislation specifies the planning conditions that will minimise the feedlot development's impact on the environment and surrounding community (ALFA 2006).

There are both positive and negative environmental issues in relation to feedlots. Finishing cattle in feedlots is more efficient than finishing cattle on grass because feedlot cattle reach market specifications faster than those on grass. Feedlots use less land per unit of output so there is less pressure on the environment and, as a consequence, there are less greenhouse gas emissions. Feedlot cattle have a lower carbon footprint per kg of beef produced compared with grass-fed cattle (ALFA 2006; Peters *et al*. 2010); there is ongoing research to quantify total emissions from feedlots using life cycle analysis. Greenhouse gas emissions from cattle on a western Canada farm were higher from breeding cows (79% of total on-farm emissions) compared with feedlot cattle (backgrounders 7%, finishers 9%) (Beauchemin *et al*. 2010).

The negative environmental issues related to beef cattle feedlots in Australia include waste (urine and faeces), noise, flies, air pollution (dust and odour) and greenhouse gases (e.g. N_2O, CH_4). Feedlot waste can be a major problem if not handled correctly. Proper waste management should maintain clean feed and pen areas, via regular pen surface cleaning and the efficient management of runoff during rainfall. Pens should be constructed to allow cleaning to be easily undertaken, including areas near feedbunks, fences, watering points and any shade areas. Inadequate waste management can contribute to an odour problem and pest problems, including flies. Once pen waste is removed it needs to be handled correctly.

Feedlots use several options for waste management:

- spreading waste onto pasture or crops for use as a natural fertiliser;
- stockpiling waste for spreading in the near future (can be sold to farms, nurseries, etc.);
- composting;
- storing runoff from pens in ponds where water evaporates and the remaining solids are used in the future as fertiliser (MLA 2012e).

Beef cattle waste is composed of ~70% faeces (20–30% dry solids) and 30% urine (3–4% dry solids) and can be produced at a rate of 5–6% of bodyweight/day. A feedlot animal weighing 450 kg will produce close to 30 kg solids/day. The material is composed of high concentrations of putrescible organic matter, nitrogen, phosphorus, microorganisms and total solids (Government of Western Australia 2002). This emphasises the importance of efficient waste removal procedures: without such procedures, waste management could become a serious issue.

Noise pollution in a feedlot is generally not from animals, but from the machinery used on the facility. Heavy vehicles entering or leaving the property before 7 a.m. and after 6 p.m. can disturb neighbours and lead to noise complaints. To prevent this, a minimum separation distance of 100 m from neighbours is recommended. Noise from the preparation of stock feed should be minimised before 7 a.m. and after 10 p.m. Sufficient enclosure and insulation for the feed preparation plant in the feedlot is necessary (Government of South Australia 2006).

Air pollution is a significant environmental issue for feedlots and can mostly be attributed to the pen surface, which is the largest source of odour in a feedlot.

Odour at a beef cattle feedlot is derived from:

- the surface of holding pens;
- feed storage;
- runoff collection and treatment ponds;
- storage and processing of solids;
- land application of effluent and solids;
- disposal of carcasses (Government of NSW 2011).

Air pollution in a feedlot can be from dust, derived from:

- movement of cattle within pens;
- storage and processing of solids;
- land application of effluent and solids;
- disposal of carcasses (Government of NSW 2011).

Odour issues are minimised by good feedlot design, construction and management. The pen surface should be kept as dry as possible. A dry pen surface can be achieved with a compacted pen surface with a consistent slope of 2–6%. If dust is an issue, water trucks may be used to dampen pen surfaces and laneways (EPA SA 2007).

Greenhouse gases (GHGs) are 'gaseous components of the atmosphere that absorb solar energy reflected from the Earth's surface' (Indira and Srividya 2012). The key GHGs related to livestock are carbon dioxide, methane and nitrous oxide (Indira and Srividya 2012). Beef cattle feedlots produced 3.5% of livestock GHG emissions, 2.4% of total agricultural emissions and 0.4% of total national GHG emissions in Australia in 2008 (ALFA 2008), while beef cattle are estimated to directly contribute 26% of US agricultural GHG emissions.

Enteric fermentation (belching and normal respiration) from ruminants is the largest contributor to Australian GHG emissions in the agricultural sector and, combined with manure, accounts for 70% of agricultural emissions (Watts 2008). Methane emission in ruminants is dependent on several factors including breed, pH of rumen fluid, ratio of acetate:propionate, methanogen population, composition of diet and amount of concentrate fed (Cottle *et al.* 2011; Sejian *et al.* 2011). Genetics can affect methane production and this has been examined by evaluating residual feed intake (Chapter 18).

Generally, cattle fed grain-based diets have reduced emission intensity (kg methane/kg gain) compared with pasture-fed cattle. Diets that are high in fermentable grains will have a rapid fermentation process. This will allow pH to be lowered in the rumen, resulting from the rapid rate of volatile fatty acid and lactic acid production, which then reduces the number of methanogens (Cottle *et al.* 2011). The amount of feed converted to methane decreases as feed intake and quality improve (Indira and Srividya 2012). Feed conversion efficiency also improves when animals are fed concentrates; they consequently reach market weight sooner, thus leading to reduced emissions over time (Hunter 2010; Indira and Srividya 2012). The inclusion of oils and oil seeds in the diet may also reduce emissions. By adding unsaturated fats to the diet, the energy density remains high and this reduces the requirement for grain concentrates (Indira and Srividya 2012). A diet that is high in fat has been shown to reduce methane production (Sejian *et al.* 2011). Several dietary additives have been proposed to assist in the reduction of methane emission. These include ionophores, antibodies, halogenated compounds (condensed tannins, saponins or essential oils) and propionate precursors (fumarate and malate) (Cottle *et al.* 2011; Indira and Srividya 2012).

Feedlots use significant amounts of water, although they are quite prudent in their usage. The water usage can be attributed to cattle drinking (78–91%), feed processing (1–6%), cattle washing (0–12%) and sundry uses (0–7%) (MLA 2011). Water supply is an essential part of all feedlot operations and water-efficient procedures, including recycling water where appropriate, need to be utilised due to the increasing lack of water availability and the threat of climate change. For licensing purposes, the total average annual water requirement for feedlots in Queensland is ~24 ML/1000 head (Skerman 2000). The average water demand in February across all of Australia for feedlots is 54 L/kg HSCW (hot standard carcass weight)/day or 50–60 L/head/day (MLA 2011).

FUTURE DIRECTIONS AND DEVELOPMENTS

The feedlot sector in Australia has capacity to increase production by 20% between 2012 and 2020. Increased demand for feedlot beef is likely from both the domestic and the international markets. However, expansion may be curtailed by environmental and animal welfare issues that will be major influences on the feedlot sector in the future. Issues such as a compulsory requirement for shade will have major financial implications and could result in some feedlots closing. Environmental concerns about greenhouse gas emissions from feedlot surfaces, manure and the cattle themselves will probably force the industry to change how manure is managed and cattle are fed, again with potential increase in costs and a reduction in feedlot numbers. A ban on HGPs and possibly ionophores will reduce feedlot efficiency and increase costs. The current issues of cattle, water and grain scarcity could worsen if climate change predictions are accurate. However, the industry is adaptable and forward-looking, so even with some substantial challenges the feedlot sector will likely continue to expand. Any expansion is more likely to be in total feedlot size, rather than total number of feedlots. Vertical integration will likely continue and feedlots that do not have access to their own cattle, grain or marketing capability will be more likely to leave the industry.

REFERENCES

ALFA (2006) Australian Lotfeeders Association. <http://www.feedlots.com.au/index.php?option=com_content&view=frontpage&Itemid=84>.

ALFA (2008) Australian Lotfeeders Association response to carbon pollution scheme green paper. Public domain submission to the Federal Government, Canberra.

ALFA (2010) Cattle on feed numbers up though challenges remain. In *ALFA Lotfeeding (July 2010)*. Fairfax Agricultural Media, Ormiston, Queensland.

ALFA (2012a) Media release: Grain fed cattle numbers down. 14 November. <http://www.feedlots.com.au/images/MR/mrsept12.pdf>.

ALFA (2012b) Data mining for feed efficiency. In *ALFA Lotfeeding*. Fairfax Agricultural Media, Ormiston, Queensland.

Andrews T, Little B (2007) Market specifications for beef cattle. <http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/148415/Market-specifications-for-beef-cattle.pdf>.

Ashmore CR, Carroll F, Doerr J, Tompkins G, Stokes H, Parker W (1973) Experimental prevention of dark-cutting meat. *Journal of Animal Science* **36**, 33–36.

AUS-MEAT (2010) *National Feedlot Accreditation Scheme Handbook 2011*. AUS-MEAT Ltd, Tingalpa, Queensland.

Bartle SJ, Preston RL, Miller MF (1994) Dietary energy source and density: effects of roughage equivalent, tallow level and steer type on feedlot performance and carcass characteristics. *Journal of Animal Science* **72**, 1943–1953.

Beatty D, Barnes A, Pethick DW, Taylor E, Dunshea FR (2004) *Bos indicus* cattle can maintain feed intake and fat reserves in response to heat stress better than *Bos taurus* cattle. *Journal of Animal and Feed Sciences* **13**(supp. 1), 619–622.

Beauchemin KA, Janzen HH, Little SM, McAllister TA, McGinn SM (2010) Lifecycle assessment of greenhouse gas emissions from beef production in western Canada. *Agricultural Systems* **103**(6), 371–379. doi:10.1016/j.agsy.2010.03.008.

Beede DK, Collier RJ (1986) Potential nutritional strategies for intensively managed cattle during thermal stress. *Journal of Animal Science* **62**, 543–554.

Beede DK, Shearer JK (1991) Nutritional management of dairy cattle during hot weather. *Agri-Practice* **12**, 5–13.

Bennett IL, Finch VA, Holmes CR (1985) Time spent in shade and its relationship with physiological factors of thermoregulation in three breeds of cattle. *Applied Animal Behaviour Science* **13**, 227–236. doi:10.1016/0168-1591(85)90046-2.

Beretta V, Simeone A, Elizalde JC, Franco J, Bentancur O, Ferrés A, Ayçaguer S, Iriñiz J, Martínez V (2010) Alternative fibre sources for steers and calves fed high-grain feedlot diets. *Animal Production Science* **50**, 410–413. doi:10.1071/AN09173.

Blackshaw AW, Blackshaw JK (1994) Heat stress in cattle and the effect of shade on production and behaviour: a review. *Australian Journal of Experimental Agriculture* **34**, 285–295. doi:10.1071/EA9940285.

Brandt RT, Anderson SJ (1990) Supplemental fat source affects feedlot performance and carcass traits of finishing yearling steers and estimated diet net energy value. *Journal of Animal Science* **68**, 2208–2216.

Brown-Brandl TM, Nienaber JA, Eigenberg RA, Hahn GL, Freetly H (2003) Thermoregulatory responses of feeder cattle. *Journal of Thermal Biology* **28**, 149–157. doi:10.1016/S0306-4565(02)00052-9.

Byrne T, Lott S, Gaughan JB (2005) *Refinement of the Heat Load Index*. Meat and Livestock Association, Sydney.

Buffington DE, Collier RJ, Canton GH (1983) Shade management system to reduce heat stress for dairy cows in hot, humid climates. *Transactions of the American Society of Agricultural Engineers* **26**, 1798–1802.

Burrin DG, Stock RA, Britton RA (1988) Monensin level during grain adaptation and finishing performance in cattle. *Journal of Animal Science* **66**, 513–521.

Cattle Council of Australia (2008) HGPs and the cattle industry. <http://www.cattlecouncil.com.au/HGP>.

Chappell G (1993) Australian feedlots and overseas markets. In *Recent Advances in Animal Nutrition in Australia 1993*. (Ed. DJ Farrell) pp. 137–144. University of New England Press, Armidale.

Coles (2010) Media release: Coles hormone-free beef to improve eating quality for customers. <http://www.coles.com.au/Portals/0/content/pdf/News/Coles%20HGP-free%20beef%20announcement.pdf>.

Commonwealth of Australia (2007) Examination of the prices paid to farmers for livestock and the prices paid by Australian consumers for red meat. Report to the Minister for Agriculture, Fisheries and Forestry. <http://www.accc.gov.au/content/item.phtml?itemId=780673&nodeId=73415507c116dc53beac4996ad1bb75a&fn=Examination+of+livestock.pdf>.

Condon J (2013) *Beef Central: MSA Grading Numbers Rise 35pc in 2012*. <http://www.beefcentral.com/trade/article/2924>.

Conrad JH (1985) Feeding of farm animals in hot and cold environments. In *Stress Physiology in Livestock*. (Ed. MK Yousef) vol. II. CRC Press, Boca Raton.

Cottle DJ, Nolan JV, Wiedemann SG (2011) Ruminant enteric methane mitigation: a review. *Animal Production Science* **51**, 491–514. doi:10.1071/AN10163.

Cooper B (2012) Grainfed beef primed to grow. In *ALFA Lotfeeding (November 2012).* Fairfax Agricultural Media, Ormiston, Queensland.

DAFF Qld (2012a) *Beef Cattle Feedlots: Back to Back Design*. <http://www.daff.qld.gov.au/4789_20306.htm>.

DAFF Qld (2012b) *Beef Cattle Feedlot Design: Round the Hill*. <http://www.daff.qld.gov.au/4789_20291.htm>.

DAFF Qld (2012c) *Detailed Design Principles*. <http://www.daff.qld.gov.au/4789_20247.htm>.

Dalquist JM (1993) Minimising the effects of environmental stress of finishing in feedlot cattle. MSc thesis. Graduate College, University of Nebraska.

DPI Vic (2011) *Opportunity Lot Feeding of Beef Cattle*. <http://www.dpi.vic.gov.au/agriculture/beef-and-sheep/beef/feeding-and-nutrition/opportunity-lot-feeding>.

DPI Vic (2012) *Victorian Code for Cattle Feedlots August 1995*. <http://www.dpi.vic.gov.au/agriculture/about-agriculture/legislation-regulation/all-acts/code-for-cattle-feedlots/feedlots-august-1995>.

Duff GC, Gaylean ML (2006) Board invited review: recent advances in management of highly stressed, newly received feedlot cattle. *Journal of Animal Science* **85**, 823–840. doi:10.2527/jas.2006-501.

Edwards AJ (1996) Respiratory diseases of feedlot cattle in the central USA. *Bovine Practitioner* **30**, 5–7

Ellis JA (2001) The immunology of the bovine respiratory disease complex. *Veterinary Clinic of Food Animals* **17**, 535–549.

EPA SA (2007) *Cattle Feedlots*. <http://www.epa.sa.gov.au/xstd_files/Industry/Guideline/ea_cattle.pdf>.

Firrell C (2011) NFAS rules and standards. In *Proceedings of BeefWorks 2011*. 5–6 October, Toowoomba. pp.13–14. Australian Lot Feeders Association, Sydney.

Forster SJ (2012) *Feed Consumption and Liveweight Gain*. <http://futurebeef.com.au/topics/feedlots/beef-cattle-feedlots-feed-consumption-and-liveweight-gain/>.

FutureBeef (2012) *Feedlots*. <http://futurebeef.com.au/topics/feedlots>.

Gardener BA, Dolezal HG, Bryant LK, Owens FN, Smith RA (1999) Health of finishing steers: effects on performance, carcass traits and meat tenderness. *Journal of Animal Science* **77**, 3168–3175.

Gaughan JB (2002) Respiration rate and rectal temperature response of feedlot cattle in dynamic, thermally challenging environments. PhD thesis. School of Animal Studies, University of Queensland.

Gaughan JB, Goopy J (2002) *Excessive Heat Load Index for Feedlot Cattle.* FLOT. 316. Meat and Livestock Australia, Sydney.

Gaughan JB, Mader TL, Holt SM, Lisle A (2008) A new heat load index for feedlot cattle. *Journal of Animal Science* **86**, 226–234. doi:10.2527/jas.2007-0305.

Gaughan JB, Mader TL, Young BA (1996) Effect of feeding regime on feed intake of cattle exposed to heat. *Proceedings of the Australian Society of Animal Production* **21**, 223–226.

Gaughan JB, Bonner S, Loxton I, Mader TL, Lisle A, Lawrence R (2010) Effect of shade on body temperature and performance of feedlot cattle. *Journal of Animal Science* **88**, 4056–4067. doi:10.2527/jas.2010-2987.

Gaylean ML, Defoor PJ (2003) Effects of roughage source and level on intake by feedlot cattle. *Journal of Animal Science* **81**, E8–E16.

George L (2012) Feed grain fears. In *ALFA Lotfeeding (November 2012).* Fairfax Agricultural Media, rmiston, Queensland.

Gleeson T, Hooper S, Martin P, Riley D, Shafron W (2002) *Australian Beef Industry 2002*. Australian Bureau of Agricultural and Resource Economics, Canberra.

Government of NSW (2004) *The Feedlot Ration*. <http://www.dpi.nsw.gov.au/agriculture/livestock/beef/feed/publications/lotfeeding/ration>.

Government of NSW (2011) *Air Quality Guidance Note: Beef Cattle Feedlots*. <http://www.environment.nsw.gov.au/resources/air/mod3p3compstruc07268.pdf>.

Government of South Australia (2006) *Guidelines for the Establishment and Operation of Cattle Feedlots in South Australia*. <http://www.epa.sa.gov.au/xstd_files/Waste/Guideline/cattle.pdf>.

Government of Western Australia (2002) *Guidelines for the Environmental Management of Beef Cattle Feedlots in Western Australia*. <http://www.agric.wa.gov.au/objtwr/imported_assets/content/aap/bc/nut/bull4550.pdf>.

Growsafe Ltd (2011) *GrowSafe Feed Intake and Behaviour Monitoring Systems*. <http://www.growsafe.com/tech_gsb.php>.

Hahn GL, Mader TL (1997) Heat waves in relation to thermoregulation, feeding behaviour and mortality of feedlot cattle. In *Livestock Environment V. Proceedings of the 5th International Livestock Environment Symposium*. ASAE, St Joseph, Missouri.

Hall AB (2000) Body heat in the dairy cow. PhD thesis. School of Animal Studies, University of Queensland.

Hansen S (2012) Creating opportunities for grainfed beef supply chains. In *Proceedings of BeefEx 2012*, 9–11 October, Ashmore. pp. 19–21. Australian Lot Feeders Association, Sydney.

Hoffman WA, Hearnshaw H (1996) Growth promotant (Revalor) increased liveweight gains while maintaining desirable carcase traits in feedlot finished steers. *Proceedings of the Australian Society of Animal Production*, **21**.

Hunter RA (2010) Hormonal growth promotant usage in the Australian beef industry *Animal Production Science* **50**, 637–659. doi:10.1071/AN09120.

IBISWorld (2012) *IBISWorld Industry Report: Beef Cattle Farming in Australia*. <http://clients.ibisworld.com.au/industryau/default.aspx?indid=17>.

Indira D, Srividya G (2012) Reducing the livestock related greenhouse gases emission. *Veterinary World* **5**(4), 244–247. doi:10.5455/vetworld.2012.244-247.

Katestone (2012) *Risk Assessment Program*. <http://nws-katestone.com.au/>.

Klopfenstein TJ, Erickson GE, Bremer VR (2008) Board- invited review: use of distillers by-products in the beef cattle feeding industry. *Journal of Animal Science* **86**, 1223–1231. doi:10.2527/jas.2007-0550.

Kolath WH, Huisma C, Kerley MS (2007) Case study: an evaluation of the potential to measure real-time body weight of feedlot cattle. *Professional Animal Scientist* **23**, 295–299.

Loneragan GH, Thomson DU, Montgomery DL, Mason GL, Larson RL (2005) Prevalence, outcome and health consequences associated with persistent infection with bovine viral diarrhoea virus in feedlot cattle. *Journal of the American Veterinary Medical Association* **226**(4), 595–601. doi:10.2460/javma.2005.226.595.

Mader TL, Gaughan JB, Young BA (1999) Feedlot diet roughage level for Hereford cattle exposed to excessive heat load. *Professional Animal Scientist* **15**, 53–62.

Mader TL, Holt SM, Hahn GL, Davis MS, Spiers DE (2002) Feeding strategies for managing heat load in feedlot cattle. *Journal of Animal Science* **80**, 2373–2382.

Mader TL (2003) Environmental stress in confined beef cattle. *Journal of Animal Science* **81**, E110–E119.

McRae T (2012) *Australian Cattle Industry Projections: Mid-year Update*. Meat and Livestock Australia, Sydney.

McVeigh JM, Tarrant PV (1982) Behavioural stress and skeletal muscle glycogen metabolism in young bulls. *Journal of Animal Science* **54**, 790–795.

MLA (2002) *Beef Sheet Full Set*. <http://www.mla.com.au/files/8243d4d2-e31b-4848-aff7-9ff700f982a8/beef-sheet-full-set.pdf>.

MLA (2006) *Tips and Tools: Feedlots*. Meat and Livestock Australia, Sydney.

MLA (2010a) *Cattle and HGPs*. <http://www.mla.com.au/files/7e66037f-1b91-48f1-82a4-9de90113ba83/cattle-and-hgps.pdf>.

MLA (2010b) *Meat Standards Australia Beef Information Kit*. Meat and Livestock Australia, Sydney.

MLA (2011) *Australian Red Meat 2000–2010: A Turbulent Decade, A Vibrant Industry*. Meat and Livestock Australia, Sydney.

MLA (2012a) *Australian Cattle Industry Projections*. <http://www.mla.com.au/Prices-and-markets/Trends-and-analysis/Beef/Forecasts/MLA-Australian-cattle-industry-projections-2012/5-Australian-cattle-industry-projections-feedlot-activity>.

MLA (2012b) *Beef*. <http://www.mla.com.au/prices-and-markets/overseas-markets/market-access/beef>.

MLA (2012c) *MSA Fact Sheets*. Meat and Livestock Australia, Sydney.

MLA (2012d) *Nutrition*. <http://www.mla.com.au/Livestock-production/Feeding-finishing-and-nutrition/Lotfeeding-and-intensive-finishing/Nutrition>.

MLA (2012e) *Odour and Waste Management*. <http://www.mla.com.au/Livestock-production/Feeding-finishing-and-nutrition/Lotfeeding-and-intensive-finishing/Odour-and-waste-management>.

MLA (2012f) *Lotfeeding Brief: March 2012*. Meat and Livestock Australia, Sydney.

Myers F (2012) *Feedlot Figures Hold Steady*. <http://www.weeklytimesnow.com.au/article/2012/11/29/550672_business-news.html>.

NRC (1981) *Effect of Environment on Nutrient Requirements of Domestic Animals*. National Research Council, Washington DC.

Office of the USTR (2012) *US–Korea Free Trade Agreement*. <http://www.ustr.gov/trade-agreements/free-trade-agreements/korus-fta>.

Peters GM, Rowley HV, Wiedemann S, Tucker R, Short MD, Schulz M (2010) Red meat production in Australia: life cycle assessment and comparison with overseas studies. *Environmental Science and Technology* **44**, 1327–1332. doi:10.1021/es901131e.

Pfizer Animal Health (2007) Understanding BVDV. Pfizer Animal Health, Sydney.

Polkinghorne R, Thompson JM, Watson R, Gee A, Porter M (2008) Evolution of the Meat Standards Australia (MSA) beef grading system. *Australian Journal of Experimental Agriculture* **48**, 1351–1359. doi:10.1071/EA07177.

Primary Industries Standing Committee (2004) *Model Code of Practice for the Welfare of Animals*. CSIRO, Melbourne.

Ray DE, Roubicek CB (1971) Behaviour of feedlot cattle in two seasons. *Journal of Animal Science* **33**, 72–76.

Raupach M, Fraser P (2011) Climate and greenhouse gases. In *Climate Change*. (Eds H Cleugh, M Stafford-Smith, M Battaglia, P Graham) ch. 2. CSIRO Publishing, Melbourne. <http://www.csiro.au/Outcomes/Climate/Climate-Change-Book.aspx>.

Reinhardt CD, Brandt RT (1994) Effect of morning vs. evening feeding of limit-fed Holsteins during summer months. In *Cattlemen's Day Rep. 704*. Kansas State Agricultural Experimental Station, Manhattan.

Secrist DS, Owens FN, Gill DR (1997) Effects of vitamin E on performance of feedlot cattle: a review. *Professional Animal Scientist* **13**, 47–54.

Sejian V, Lal R, Lakritz J, Ezeji T (2011) Measurement and prediction of enteric methane emission. *International Journal of Biometeorology* **55**, 1–16. doi:10.1007/s00484-010-0356-7.

Shearer JK, Beede DK (1990) Thermoregulation and physiological responses of dairy cattle in hot weather. *Agri-Practice* **11**(4), 5–17.

Sherman EL, Nkrumah JD, Li C, Bartusiak R, Murdoch B, Moore SS (2009) Fine mapping quantitative trait loci for feed intake and feed efficiency in beef cattle. *Journal of Animal Science* **87**, 37–45. doi:10.2527/jas.2008-0876.

Silanikove K (2000) Effects of heat stress in the welfare of extensively managed domestic ruminants. *Livestock Production Science* **67**, 1–18. doi:10.1016/S0301-6226(00)00162-7.

Skerman A (2000) *Reference Manual for the Establishment and Operation of Beef Cattle Feedlots in Queensland*. Department of Primary Industries and Fisheries, Brisbane.

Smith Thomas H (2009) *Cattle Health Handbook*. Storey Publishing, USA.

Sneath R, Bath G (2012) *Diet Components*. <http://futurebeef.com.au/topics/feedlots/beef-cattle-feedlots-diet-components/>.

Snowder GD, Van Vleck LD, Cundiff LV, Bennett GL, Koohmaraaie M, Dikeman ME (2007) Bovine respiratory disease in feedlot cattle: phenotypic, environmental, and genetic correlations with growth, carcass and longissimus muscle palatability traits. *Journal of Animal Science* **85**, 1885–1892. doi:10.2527/jas.2007-0008.

Spears JW (1990) Ionophores and nutrient digestion and absorption in ruminants. American Institute of Nutrition **120**, 632–638.

SSCRRA (1992) Beef cattle feedlots in Australia. Report of the Senate Standing Committee on Rural and Regional Affairs, December 1992. Senate Printing Unit, Canberra.

Stock RA, Sindt MH, Parrott JC, Goedeken FK (1990) Effects of grain type, roughage level and monensin level on finishing cattle performance. *Journal of Animal Science* **68**, 3441–3455.

Streeter MN, Branine M, Whitley McCollum FT (2000) *Feeding Behaviour of Feedlot Cattle: Does Behaviour Change with Health Status, Environmental Conditions and Performance Level?* Plains Nutrition Council Meeting, San Antonio, Texas.

Sullivan ML (2011) Modification of pen microclimate to improve the productivity and welfare of feedlot cattle. PhD thesis. School of Agriculture and Food Sciences, University of Queensland.

Sullivan ML, Cawdell-Smith AJ, Mader TL, Gaughan JB (2011) Effect of shade area on performance and welfare of short fed feedlot cattle. *Journal of Animal Science* **89**, 2911–2925. doi:10.2527/jas.2010-3152.

Swan (2012) *US Heatwave to Send Australian Food Prices Higher*. <http://www.smh.com.au/business/markets/us-heatwave-to-send-australian-food-prices-higher-20120709-21r3w.html#ixzz20MMh2gnF>.

Tucker RW, Watts PJ, Lott SL, Jukes P (1991) *Lot Feeding in Australia: A Survey of the Australian Lot Feeding Industry*. Department of Primary Industries, Brisbane.

Vander Pol KJ, Luebbe MK, Crawford GI, Erickson GE, Klopfenstein TJ (2009) Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. *Journal of Animal Science* **87**(2), 639–652. doi:10.2527/jas.2008-1036.

Watts P (2008*) The Farts, Facts and Fiction on Greenhouse Emissions and the Lotfeeding Industry*. FSA Consulting. <http://www.fsaconsulting.net/fsa/docs/Watts_BEEFEX_2008_Presentation.PDF>.

Watson R (2008) Meta-analysis of the published effects of HGP use on beef palatability in steers as measured by objective and sensory testing. *Australian Journal of Experimental Agriculture* **48**, 1425–1433. doi:10.1071/EA07174.

Yang WZ, Li YL, McAllister TA, McKinnon JJ, Beauchemin KA (2012) Wheat distillers grains in feedlot cattle diets: feeding behaviour, growth performance, carcass characteristics, and blood metabolites. *Journal of Animal Science* **90**, 1301–1310. doi:10.2527/jas.2011-4372.

Zinn RA, Plascencia A (1996) Effects of forage level on the comparative feeding value of supplemental fat in growing-finishing diets for feedlot cattle. *Journal of Animal Science* **74**, 1194–1201.

This page intentionally left blank

12 Live cattle export industry

D.P. Poppi

INTRODUCTION

Cattle have been transported between countries by sea for a long period. In Australia, in 1788 the First Fleet brought cattle loaded at the Cape of Good Hope, taking a few months to reach Australia (Daly 1960). In America, the first colonists brought cattle by sea in 1606 (Swanson and Morrow-Tesch 2001) and by the 1700s this had developed into a large live export industry from America to the West Indies. The journeys all took several months and losses could be high, depending on the sailing conditions of the time. Transport today is much quicker (days and weeks) and subject to regulations not even considered in that early period.

There were many attempts to develop a live export trade in Australia, especially in the more remote areas of northern Australia. The traditional approach of moving cattle to major population centres (Adelaide, Melbourne, Sydney and Brisbane) along stock routes led to the popular idea of the drover and a lifestyle that was romanticised. The reality was different, with long periods needed to take cattle from the north to these centres, disputes along the stock routes, shortage of feed (forage and edible shrubs) and sometimes loss of weight of cattle and mortalities. Drovers were paid on the number and condition of cattle: it was in their interest to have no losses and to maintain or increase weight, but the prevailing conditions of the stock routes meant that this was not always achievable. Stations closer to the major centres were at an advantage and the large distances that needed to be travelled from northern Australia meant that the region always struggled to provide cattle and to make money. Various individuals, such as Sir Sidney Kidman, established a series of stations along the stock routes following the pattern of rainfall or water flows (Channel Country) to allow cattle to be moved to the major centres with some guarantee of feed supply. The enterprise as a whole could be drought-proofed (Bowen 1995). The Kidman Co. today, along with many of the larger pastoral companies, still maintains this successful approach. However, smaller companies and family units do not have this advantage and their cost structure for transport restricts their market access.

Some of the first efforts to find alternative markets to the major centres of Australia were made by the Durack family (Durack 1983) which, from its Kimberly base (in northern Australia), looked for alternative markets for their beef after the decline of the gold rush market. By 1894 a jetty was completed at Wyndham and by 1897 ~7000 cattle were being shipped from there to the Philippines (Durack 1983). Rose (1960) indicated that, by 1893, ~2000 cattle were being shipped annually from Darwin to Batavia (Indonesia) and Singapore. These countries are still the major markets for the live export trade of cattle from Australia. Since that period, the trade has fluctuated widely but from 1975 it gradually increased from around 20 000, reaching ~900 000 cattle in 2009 being exported live mainly to markets in South-East Asia but also to the Middle East, North Africa and Turkey (Ransley 2008; Farmer 2011). Darwin accounts for about one-third of the cattle exported live from Australia (LiveLink 2011).

The ships and conditions have changed markedly since the days when Governor Phillip sailed from Good Hope and commercial markets were established from Darwin and Wyndham, but so have the views of the population on animal welfare and ethics. Those regions have the advantage of lower land values than other regions in Australia, with less competition from other enterprises for land use, but nevertheless still need profitable market access. The development of beef roads in the 1960s enabled road transport to compete with the established rail networks but this still involved distances of 2000–3500 km to reach domestic markets. Costs are still high and the main processing markets near the capital cities are restricted in competition (i.e. few owners); the live export trade provides competition and higher prices to the northern region of Australia.

MARKETS

The live export market ranged from ~800 000–900 000 cattle per annum in 2008–10 but the disruption of the trade with Indonesia during 2011–12 caused a substantial decline (Table 12.1). Thompson and Martin (2012) forecast that the market could drop to 500 000 cattle in 2012. Indonesia accounted for the majority of the trade (~77%) over the decade to 2010 (Farmer 2011). Cattle are sourced from both southern and northern Australia, although the majority come from the north. They better meet the guidelines for travel from the southern to northern hemispheres and the breed type is well received in Asia. Other markets have a preference for *Bos taurus* genotypes, so each market is a little different. As an example of the different markets, 796 188 cattle were exported for slaughter in 2010: 517 418 went to Indonesia, 64 338 to Turkey, 56 441 to Egypt, 19 257 to Jordan, 16 344 to Malaysia and 16 155 to the Philippines, to name a few of the 17 major countries to which cattle were exported (Farmer 2011).

The major states exporting cattle are the Northern Territory (NT), Queensland and Western Australia. Over the period 2009–11 the NT accounted for 36%, Queensland 12% and Western Australia 43% of live export cattle numbers. Darwin was the major port, accounting for 58% of cattle exported from the northern regions, whereas Fremantle was the major port for cattle going to the Middle East, Turkey and North Africa. In the financial year ending June 2011, total exports were ~805 000 head with a value of AUD$660 million. Indonesia accounted for 57% of the trade in that year (down from 75% the previous year) with South-East Asia in total accounting for 62%, the Middle East 27%, North Asia 8% and 3% to other markets (LiveLink 2011). Total numbers declined in financial year ending June 2012 to 683 000 head, with Indonesia 55%, South-East Asia (total) 62%, the Middle East 20% and North Asia 11% (Table 12.1).

Table 12.1: Live export (head) by destination and livestock slaughter (million head) within Australia

	2009–10	2010–11	2011–12
Indonesia	718 074	457 362	376 148
Philippines	14 789	15 858	23 903
Malaysia	5531	20 580	19 963
Turkey	1230	104 355	37 432
Total live export	957 533	805 005	683 293
Livestock slaughter in Australia	7.78 million	7.46 million	7.37 million

Differences occur in various sources because of use of calendar year or financial year statistics.
Source: MLA (2012a).

The Centre for International Economics (CIE 2011) reviewed the contribution to the economy of the live export industry. It found that 74% of the on-board value of cattle was accounted for by sale price to producers, that without the live export industry the saleyard price of cattle across Australia would have been ~4% lower and that sale prices in northern Australia, the main live exporting region, would decline by ~24%. These figures outline the importance of the live export trade to producers in the northern regions. A further benefit has been the increase in land value of northern enterprises as a consequence of having a defined and valuable accessible market for their product.

Live export cattle are a significant number of the total cattle killed within Australia if it is assumed that most of the cattle which are exported are eventually slaughtered in the importing country. Approximately 7.9–8.4 million cattle were slaughtered annually within Australia during 2009–12 with an additional 728 000–870 000 being sold for live export in the same period, or ~8.9% of total animals destined for slaughter (Thompson and Martin 2012). This comes from a total cattle population of 24–27.6 million or ~35% of the total cattle population (Thompson and Martin 2012; Chapter 4).

ISSUES FACING THE LIVE EXPORT INDUSTRY

Food security

The issues facing the live export industry are of a commercial and a welfare nature. Commercial issues relate simply to the value that beef producers can get for their product from various markets, whether they are slaughtered within Australia for boxed beef or exported live (to be fattened in another country for local slaughter to meet religious and cultural requirements) or value-added by local fattening operations. There has been an argument about the inability of developing countries to refrigerate meat and so the unsuitability of boxed beef in those markets. However, an increasing middle class and supermarkets in these countries means that boxed beef has potential to increase as a source of supply. Small corner stores are increasing in number throughout Asia and these mini-markets are able to hold refrigerated meat for sale, further increasing the opportunities for boxed beef in Asia. However, this is still a minor outlet (Pingali 2006; Morey 2011). At present and for a considerable future, the wet market (freshly killed meat products) in Asia will still be the major source of meat for the population meeting religious and cultural requirements. These markets are not guaranteed.

Countries, for various political and economic reasons, have well-intentioned policies to support their local industries to become self-sufficient in various products, including food. Food security has been an overriding policy issue throughout history in all parts of the world. It is not a new phenomenon, nor are the aspirations of countries to develop sound industries which keep people employed and increase gross domestic product. In this regard, meat is no different from a manufacturing industry or information technology industry. Political sensitivity is important, as are the development of free trade agreements and the World Trade Agreement. With the desire to have free access to better markets for manufacturing products using cheaper labour, developing countries often struggle with free trade in other industries such as food. The markets for the live export trade and boxed beef are not guaranteed in these regions. The development of free trade agreements or similar policies is important to maintain these markets and remove barriers or whimsical political decisions from both sides. The boxed beef trade also increases competition from other countries (e.g. Brazil) to supply into these markets at very competitive prices (Chapter 6). All the projections suggest that the demand for meat will increase markedly as the Asian region becomes more affluent (Pingali 2006). Market access by other countries, either through live export or boxed beef, will also increase. Australia has no competitive advantage other than its location (for live export) and its reputation for quality-assured product (for boxed beef) and the price producers receive will always face fierce competition from the world market.

Cultural preferences

There are often cultural and religious reasons for the market in live export. These are good reasons which have a strong case. Various Islamic festivals require ritual slaughter and distribution of fresh meat throughout the community, and some countries can struggle to meet these requirements. The changing time of the calendar year for these festivals also imposes restrictions on supply and on the type of animal. It can be difficult, with the seasonal nature of cattle supply from northern Australia, to meet these requirements. However, religious festivals do not solely drive the market for live export: it is driven by the need for a year-round supply of fresh meat, with finishing operations in the market country. Some countries (e.g. New Zealand) made a policy decision not to be involved in the live export trade, instead developing local slaughter procedures which meet halal requirements and exporting refrigerated product. Australia also has abattoirs that meet halal requirements.

Animal transport

A broader view of the transport of animals needs to transcend national boundaries. Animals in Australia can be transported 2000–3500 km by road to a region for fattening in a feedlot or on improved pasture. Transport to Indonesia or the Philippines for fattening in a feedlot is not that dissimilar. Feedlots in Australia use grain whereas feedlots in Asia use crop by-products as the major feed ingredient. The crop–livestock systems in Asia have the advantage of utilising animals within a mainly cropping enterprise without direct competition between animals and humans for the feed resource. Even large feedlot companies in Asia use a large amount of by-products; if they use specialised crop products (e.g. maize silage), the supply of these provides a major industry for local farmers. The moral issue of growing maize silage instead of rice does not really arise if the returns are such that a farmer can move from subsistence to a better lifestyle. The treatment of animals, including their slaughter, in the destination country may be an issue. The attitude of the destination country about animal welfare may differ markedly from that of the source country, in this case Australia. How do we deal with this? In the first instance, Australia provides the animals and those involved in the trade have a responsibility to ensure that their treatment meets the standards expected of Australian producers and the general public, and to ensure that international treaties and obligations are met, such as standards outlined in the World Organisation for Animal Health (OIE 2011a, b, c) to which most importing nations are signatories. On the other hand, there is also a requirement to recognise cultural and religious practices of the destination country. Method of slaughter is one practice where differing attitudes can be difficult to reconcile. Sometimes problems arise from difficulty in handling Australian cattle due to their temperament, in conditions where local animals are used to being tethered and led. In many situations, discussions by all parties are able to resolve the issue satisfactorily but once western concepts are stridently advocated the parties tend to become fixed in their view and entrenched attitudes become difficult to change. Working together to find a solution is a much better approach. Provision of some infrastructure, training and stunning procedures can work in an atmosphere of mutual respect. However, sometimes there are acts which are not acceptable to both countries or the main players in the trade; suitable quality assurance and inspection programs need to be implemented to ensure public confidence in the adherence to those principles. The Australian government has passed legislation – the Exporter Supply Chain Assurance System (DAFF 2012) – that ensures individual animals are tracked all the way to slaughter and that strict criteria are met.

Value-adding within Australia

The live export trade also faces criticism that it is exporting jobs off-shore. There is no doubt that further jobs could be created in the meat-processing industry if all animals were killed and processed within Australia. But where does the benefit lie? The processing industry in Australia is dominated by a few companies. These could employ more labour. However, there are a large number of people employed in the live export trade in the form of transport operators, backgrounding operations, feed companies etc. This rapidly became apparent when the live export of animals to Indonesia was temporarily halted in 2011, so labour should not be looked at in isolation (Farmer 2011). The processing plants are not located close to the north and significant transport distances are involved. There are restrictions on time of travel, vehicle design etc. which are under scrutiny. Companies appear to have no desire to move processing plants further north, unless subsidised by the Australian government, and indeed have consolidated most operations further south, which will only exacerbate the problem of road transport in the future. Part of the problem is the seasonal nature of supply and the difficulties of collecting and moving cattle in the wet season in the north. It would make more sense to process animals closer to the source of production: the argument is made that this indeed happens with animals processed closer to the feedlots or better endowed zones for pasture production. Processing plants closer to northern region grazing lands would give the impetus for development of localised finishing industries. In the present circumstances these would not be competitive, largely because of transport costs. Processing plants in the north would remove many of the welfare concerns about transport. An argument against locating processing plants in northern Australia is the difficulty of getting labour. This is indeed the case, but various governments and unions have restricted working visas making it harder for temporary workers to go to remote areas of Australia, so companies have located near major population centres.

Animal welfare

The welfare and ethics of animal trade are major issues faced by the live export industry. Many think they are the only issues, but there are other factors as discussed in this section. Phillips (2005) outlined the ethical issues associated with the live export trade but they apply equally to any trade in animals. These issues can be broadly described as:

- the sentience of animals;
- a philosophical view of animal speciation and order;
- moral obligations and ethics of an individual, society and professional group;
- range of groups who are closely or distantly involved in the use of animals;
- positive and negative aspects of the use of animals;
- media presentation;
- the majority view in a democratic society.

There needs to be a distinction between the ethics of the use of animals and the welfare of those animals (Chapter 13). In the first instance, Phillips (2005) outlined the extreme arguments made on both sides of the debate – by those who recognise individual animal rights as equal to or even overriding human rights and those who argue that human rights take precedence over all other animals. This is an ethical and moral argument about the use of animals and their rights. It is one upon which individuals need to make an informed decision. Welfare of animals presupposes in many ways that a decision has been made about the use of animals and it is then imperative to apply the highest standards of welfare in the husbandry of that animal. Urban people are increasingly divorced from day-to-day contact with farm animals, while producers are increasingly conditioned to the prevailing scenarios facing the husbandry of animals (Phillips 2005; Petherick 2005). Producers do aspire to the highest welfare of their animals but there may be competing welfare outcomes by doing or not doing certain procedures (e.g. castration and dehorning) (Petherick 2005). They become conditioned to these procedures and sometimes it requires a major incident before the approach is questioned. Examples are the mulesing debate in the sheep industry and the slaughter procedures of some countries to which Australia exports live animals. Welfare standards are a community consciousness which changes with time and is increasingly driven by consumers mostly within affluent societies. It seems selective to apply welfare standards only to farm animals, when pet owners seemingly ignore the adverse effects of cats on native wildlife. Profitable production systems enable producers to apply the highest welfare standards and the live export trade has enabled producers in the north to apply better husbandry procedures on the farm. The welfare of animals in transit, at arrival and at final slaughter needs to be addressed, and requirements do change. The industry needs to embrace the changes as they largely align with its own aspirations for animal production. This is discussed later in the chapter; this section has outlined the philosophical basis of the ethical and welfare issues facing the live export industry.

ADVANTAGES AND DISADVANTAGES OF THE LIVE EXPORT INDUSTRY

Advantages

The live export industry has provided an alternative market for cattle from northern Australia and as such has sustained higher prices in that region (Chapter 9). For other regions of Australia it simply provides another market where the laws of supply and demand dictate prices. Higher prices and greater returns have resulted in improved husbandry and management of animals. Under present production systems and annual liveweight gains (in northern Australia), it takes close to four years for an animal to reach a marketable slaughter weight for most of the boxed beef markets to which Australia exports. Much research has gone into developing productions systems that will enable animals to be finished by 2.5–3.5 years of age but these are usually uneconomic given the current costs of production, cost of transport to slaughter and $/kg carcass weight. Nevertheless, such systems do work and can be very productive biologically. For example, the irrigated pangola grass and leucaena based system in the Ord River Irrigation Area, north-west Western Australia, is among the highest-producing system/unit area in the world (Jones 1990; Petty *et al.* 1998) but sandalwood production has taken over most of the irrigated area as it is more profitable.

The advantage of a live export industry for northern Australia is that it enables a cow–calf system to function effectively in the harsh environment. Husbandry and welfare of these animals has improved dramatically. For example, for the Indonesian market, young cattle have maximum entry requirements onto a ship at ~350 kg weight which means that ~12 months after weaning, or after one wet season, young cattle are ready for export. Weaning starts around May and extends to around September–October on most properties depending on whether one or two musters are done each year. Incorporating simple management procedures such as early weaning, even if bulls are present all year, and preferential treatment of weaners ensures that the bulk of the herd have a calving pattern that falls largely within the wet season and time of better nutrition. The disastrous management practices of the past, before the brucellosis and tuberculosis eradication schemes brought in more fencing and better control of animals, have largely disappeared (Chapter 13). Extremely low body condition score of cows lactating in the dry season, P deficiency and broken bones, low survival of cows and calves were formerly common, as were low weaning rates of around 50–60%. The surveys of Bortolussi *et al.* (2005a) suggested increases across the region of ~8% in weaning rates from 1990 to 1996 as a consequence of better management, with mean weaning rates of 72% and 63% for Queensland and the Northern Territory respectively (Chapter 9). The profitable market for weaners has enabled these much better husbandry and welfare outcomes. The Wambiana project (O'Reagain *et al.* 2011) and the Pigeon Hole project (Hunt *et al.* 2007, Petty *et al.* 2012) showed the advantages of these animal management practices for the animal, landscape and financial returns. Similar outcomes would have resulted from any alternative market to transporting cattle to slaughter facilities, but the live export trade enabled the changes to happen rapidly and provided a competitive market to maintain higher prices from meat processing companies in the south. Previously, the major market was the US ground beef market and before that there was the trade in bulk beef of low quality by overseas companies.

Breed type has been an advantage to the live export trade. Initially the northern region was opened up with British breeds, largely Shorthorn. The shift to *Bos indicus* genotypes, largely Brahman, gave rise to a cow which was tropically adapted to heat and disease (mainly cattle ticks) (Frisch and Vercoe 1984; Chapters 5, 9). This meant that survival and welfare in the cow–calf population improved markedly compared to the traditional Shorthorn cow–calf system. The offspring are favoured more in the live export trade to Asia than in the southern market, where issues about meat quality and growth rate under better nutrition and feedlots mean that the *Bos taurus* genotype is favoured (Schutt *et al*. 2009). *Bos indicus* genotypes are preferred in Asia as they originate from that region and have higher heat and disease tolerance.

Australia is free of the major cattle diseases (foot and mouth, brucellosis, tuberculosis) which impede free trade (Scoones *et al*. 2010; Chapter 13). This is not the case with many Asian, African and South American countries and so Australia has an advantage in exporting to Asia. Some countries (e.g. Indonesia), do not have foot and mouth disease, and animals and boxed beef from Australia meet strict import regulations. At this stage this provides a competitive advantage to the live export trade but there are many countries which could compete to supply of animals or boxed beef if the restrictions were relaxed.

Disadvantages

The disadvantage of live export is that it develops an industry based solely on live export: if live exports stop or are markedly reduced, as occurred recently, producers do not have an alternative supply chain into which to feed stock. This may be economically disastrous and seriously affect welfare of animals if the problem is accompanied by overgrazing and shortage of feed supplies. Similarly, no serious thought has been given to the development of alternative grazing systems or local slaughter and processing facilities nor to the development of alternative markets, particularly those aligned to lower-quality meat.

MEETING LIVE EXPORT REQUIREMENTS

The major requirement is a weight (and age) classification which varies with the importing country. This can change and countries can relax then reimpose requirements, making meeting the market specification a difficult task for producers and shipping agents. Classification can be specified for breeders or for fattening animals. Breeders are a variable market, fluctuating largely with specific schemes. The fattening animal is a steadily increasing market but is sensitive to the economic conditions of the host country. During the Asian financial crisis in 1996-97 many of the major markets (Indonesia, Malaysia and the Philippines), reduced imports markedly. Indonesia is the main market and currently there is a 350 kg weight limit on non-breeding cattle entering the country. Other markets specify other weights, for example 280–400 kg in Malaysia and 330 kg in the Philippines (Ffoulkes 2012). Most Asian feedlotters want at least 50% Brahman content but some of the larger commercial feedlots would have <50% Brahman content, reflecting a preference for genotype mixes associated with better growth rates and meat quality from an Australian meat quality perspective. Weight restrictions for sea transport are set between 200–650 kg (DAFF 2011). Steers and heifers can be sent but heifers need to be pregnancy-tested and declared not pregnant, though there have been incidents of heifers calving in the feedlot. Each market may impose specific requirements.

Australian exporters are required to document and trace animals all the way to slaughter under the Export Supply Chain Assurance System (ESCAS) and to meet other regulatory requirements (DAFF 2011). The Department of Agriculture, Fisheries and Forestry (DAFF 2012) outlined the main requirements of ESCAS:

- provide evidence of compliance with internationally agreed welfare standards;
- demonstrate control through the supply chain;
- demonstrate traceability through the supply chain;
- meet reporting and accountability requirements;
- include independent auditing.

All markets to which live export cattle are destined for slaughter were obliged to meet those requirements by the end of 2012. Australian exporters use radio-frequency identification through National Livestock Identification System (NLIS) tags to all cattle exports. This enables tracking of animals within the importing country and meets Australia’s contractual requirements for traceability under ESCAS.

Disagreement over weight limits occurs. Producers are paid on a $/kg liveweight basis and, to maximise their returns, need to produce cattle as close as possible to that maximum. Shipping agents/exporters are paid on the liveweight on disembarkation and therefore need to be under the maximum weight limit, but at the same time they make money by increasing weight during the voyage. Getting the weight wrong can result in the cattle being rejected.

Pre-shipping phase

Other chapters have described the various production systems in northern Australia (Chapter 9). Briefly the system is a cow–calf system with either some control over access to bulls or year-round mating. The key to the successful operation is a weaning process set by the time of mustering and the ability to wean down to low levels of liveweight. This increases the chances of cows cycling and conceiving before the end of the wet season. If this occurs, the calving period is reasonably concentrated with most cows having a wet season lactation. Weaning weights vary between 100 kg and 300 kg for most calves, at an average near six months of age, but this can vary widely depending on whether there are one or two mustering rounds and when these are done (Bortolussi *et al.* 2005a). With the cost of mustering increasing, some businesses are moving to one mustering event and weaning animals down to very low weights such as around 100 kg. If so, the weaned calf needs different levels of nutrition and husbandry depending on its weight (Tyler *et al.* 2012). This can be done very successfully with very good husbandry and welfare outcomes (Chapter 16).

Animals destined for live export are held for the remaining dry season, usually with very little liveweight gain. With compensatory growth over the next wet season, they will gain ~90–180 kg (generally <150 kg in northern regions) for the year and some will be ready for live export (Bortolussi *et al.* 2005b). The problems are the variable weights at weaning, the variable levels of liveweight gain in a mob over the dry and subsequent wet seasons, and hence the variable weights of cattle for entry into the shipping process (Streeter 2012). Animals need to be as close as possible to the target weight of entry: this is clearly not possible under current production systems for animals initially weaned at a young age at 80–150 kg if the target weight is close to 350 kg. These animals will need to be held for another wet season to reach target weights, or supplied with higher levels of supplement, both of which reduce profitability. The converse – animals that are born out of season and not weaned until the following year – is that they are often too heavy for entry into specific live export markets. The narrow market specifications of 280–350 kg are hard to achieve when weaning weight can vary between 80 kg and 250 kg, liveweight gain is 80–180 kg over the wet season, and many properties are unable to access or transport cattle during the wet season. Meeting weight specifications is best done by setting up the calving pattern of animals in the first place, weaning down to low weights and possibly preferentially feeding or supplementing certain weight classes, depending on the prevailing economics (McLennan and Poppi 2011).

Husbandry and training of weaners is a very important step in the live export of animals. Petherick (2005) and Tyler *et al.* (2012) have outlined some of the steps and the positive outcomes. Basically animals are held in yards, fed hay and supplements and are tailed out (i.e. moved on foot and by people on horseback) regularly over about a two- to five-day period and up to two weeks (Chapter 21). In this process they learn to follow and interact with people, accept hay and supplements and generally become quieter and adaptable to change. These are traits animals need when next mustered, weighed and transported to holding yards for live export with minimal stress.

At the time of weaning, other husbandry procedures are performed to enable management of the animal. These are castration, branding, ear notches (and increasingly the use of NLIS tags) and vaccination (Petherick 2005; Tyler *et al.* 2012). All these are stressful to the animal but occur for only a short period. After this short period of training in the yards, weaners are allocated one or more paddocks for the rest of the dry season or, in the case of large pastoral companies, they may be transported to a better region for backgrounding. If they remain on the station, the paddock is usually in a better class of country or one that has been saved specifically to provide adequate pasture mass at low stocking rates so as to maximise the level of nutrition. Preferential treatment of weaners may also be in the form of supplements. At the least, a urea-based mix is provided for nitrogen, the first limiting nutrient but, depending on liveweight, protein meals, molasses or grain/protein mixes or calf pellets may also be provided (Tyler *et al.* 2012). This ensures that light-weight weaners have a chance to reach target weights. Tyler *et al.* (2012) provide several case studies from northern Australia on the weaning and husbandry of weaners. There was a small negative association of weight at weaning with performance over the subsequent dry season but a quadratic positive response with weight gain over the subsequent wet season (Streeter 2012). Level of nutrition is still the overriding factor affecting liveweight gain but the combination of weaning weight and the liveweight target dictate the extent to which liveweight gain needs to be increased, if at all, during the dry and wet seasons which follow weaning.

The next time the animals are mustered is after the next wet season, depending on the market and the time requirement for shipping. Animals are then transported by road to holding yards ready for shipping. Any mustering of an animal not accustomed to yards, bikes, horses and helicopters is stressful and hence the advantage of training for this process during the weaner training period. Trained animals adapt readily to the changes and are more amenable in the importing country. Transport of animals within Australia is subject to strict regulations on vehicle design, duration of transport, spelling and density (DAFF 2011). Several studies underpin these regulations (Wythes *et al*. 1980, 1981, 1985a, b; Petherick 2005). In their review, Swanson and Morrow-Tesch (2001) outlined the effects of and some procedures to facilitate transport. They focused on 'calves', which they defined as under six months of age. A major issue was increased stress, as evidenced by various circulating hormones and blood chemistry, and the increased incidence of disease, in particular pneumonia and salmonella (Swanson and Morrow-Tesch 2001). However, these animals were much younger and quite different from the more mature cattle transported within Australia for collection at live export holding yards. The incidence of disease is lower in these cattle during the holding period before shipping, with the exception of bovine respiratory disease and salmonellosis in *Bos taurus* cattle from southern Australia. Coccidiosis is an intermittent problem. In the north, bovine ephemeral fever may occur sporadically in some wet seasons.

Animals are collected at the holding yards in anticipation of the scheduled arrival of a ship. This period can be stressful, as density within the yard increases and there are behavioural adaptations to new groups of animals. The weaner training the previous year becomes important in the response of animals to handling, diets and new circumstances. Animals are held in holding yards for a minimum of one day (short-haul voyages) or two days (long-haul voyages) or as long as is necessary until a shipment is collected (DAFF 2011). Long periods are avoided as they are costly. During this period cattle are gradually introduced to the ship diet, which is usually a pellet made from various ingredients to a specification of fibre and crude protein (CP) content. There is a gradual shift over a few days from a hay-based diet to a pellet-based diet but at times this has to occur more rapidly to meet a sailing date. The usual good management procedures should be followed in the provision of water, shade and space (i.e. density of stock) and there are various standard operating procedures recommended by Meat and Livestock Australia (MLA) or the exporters themselves (MLA 2007, 2008; Queensland Govt) and regulations which must be adhered to (DAFF 2011).

Hunter *et al*. (2002) outlined an example for relocating cattle for shipping and finishing in a feedlot overseas:

- road transport from the Barkly Tableland to a commercial property near Hughenden (two days; approx. 800 km);
- grazing (agistment) on pasture for 50 days;
- road transport from Hughenden to a feeding depot near Townsville (one day; approx. 400 km);
- pre-shipment adaptation period in Townsville during which they were fed the shipboard diet of pellets (six days);
- sea voyage to Philippines (11 days);
- induction to feedlot (eight days);
- fed feedlot diets for 87 days before slaughter.

Another example from the Northern Territory would be road transport to Darwin holding yards (one to two days), pre-shipment adaptation period (a few days to about two weeks), sea voyage to Indonesia (about four days), induction into feedlot (about eight to14 days), feedlot ration before slaughter (around 70 days).

The times for adaptation, sea voyage, feedlot time and relocation to slaughter vary.

The Australian government has published standards relating to the live export of animals: *Australian Standards for the Export of Livestock (Version 2.3) 2011* and *Australian Position Statement on the Export of Livestock 2011*. An extensive review in 2001 of the procedures for selecting and preparing cattle for live export underpin many of the standard operating procedures and other recommendations in place today and has directed research initiatives (Alliance Consulting and Management 2001). The main factors considered in the review were time between yarding and delivery to exporter, temperament, sex of animals, breed of animal, time of year, on-farm handling, condition score, horns and severe weather. Bovine respiratory disease was a key disease which became apparent during the pre-shipping and shipping phases. Various documents and fact sheets are available from MLA and state governments to provide advice about the selection and preparation of animals and the various regulations for live export: e.g. *Is it Fit to Export?* (MLA 2007), *Livestock Export from Queensland* (Queensland Government Fact Sheet), *Preparation of Cattle for Live Export: Tips and Tools Live Export Program* (MLA 2008).

Shipping phase

Sea transport can take from around five to 12 days (Indonesia, Malaysia, Brunei and Philippines) from northern ports to 15–30 days to the Middle East and other northern hemisphere destinations from southern ports. During this period, the exporter would prefer cattle to gain weight but not to exceed the regulated maximum liveweight. Hence cattle need diets that have a high nutritional value but do not have a high incidence of digestive upsets. Ingredients are very much determined by the port of exit. For example, in Perth, pellets may comprise straw, lupins, canola meal and barley designed to give ~8.5–10.5 MJ ME/kg DM (Accioly *et al.* 2003). In Darwin, pellets may be made of mixtures of cavalcade hay and sorghum. Lucerne pellets are also used. Other experimental rations have been studied, e.g. Hunter *et al.* (2002) reported on a high (50%) molasses diet. Pellets are preferred because of ease of distribution around the ship, storage volume and the opportunity to add minerals and vitamins and sometimes electrolytes or urine pH adjusting compounds. The key is to have animals reach high intakes quickly in the pre-shipping phase and to ensure no digestive upsets occur on board.

Several factors are important for on-board management of animals:

- diet ME content, crude protein and level of fibre;
- water;
- ammonia production;
- space and cleaning;
- heat;
- electrolytes;
- disease;
- shy feeders and sick animals;
- sea-sickness;
- pregnancy, horns and age.

Diet ME content, crude protein and level of fibre are set to maximise intake and minimise digestive upsets and abnormal behaviour by promoting rumination and salivary buffering of the rumen. Some examples have been given above, but the key consideration is cost. Ration formulation packages of various types can be used in ration design of least-cost rations with minerals and vitamins balanced with premixes. Ship numbers generally range from 3000–4000 with some large ships capable of carrying 20 000 head. With an intake of ~7.5 kg/d and journeys of five to 24days, the total amount of pelleted feed that needs to be taken on board for a 4000 head shipment ranges from 150–720 t with some provision for events which might delay the transport time. Bunk management is similar to a commercial feedlot where a small level of refusal is set so as to achieve *ad libitum* feeding but level of feeding may be restricted in some circumstances. This can lead to rapid food intake and bullying, both of which can lead to acidosis and shy feeders with inevitable health problems (Chapter 16). Hospital pens similar to those at a commercial feedlot can be set up, but the ability to do this on board ship is more limited.

An adequate amount of clean water is essential as cattle require 30–60 L/head/d or ~6–14% of liveweight, depending on genotype and ambient temperature. Ships have desalination procedures capable of producing around 600 t of water/day. Any major issue with the ship or entry permission into the country of destination can cause major production and welfare issues. Hunter *et al.* (2002) gave an example of feed having to be restricted due to a slower than anticipated speed as a result of engine problems extending the journey by 3.5 days. The *MV Cormo* incident in 2003, where sheep were not allowed to be unloaded in Saudi Arabia, illustrated the major problem of limited food on board a ship and the emergency government action required to find an alternative country that would take the sheep before wholesale euthanasia was required (Ransley 2008; Stinson 2008). The *MV Becrux* incident in 2002, where there was high cattle mortality due to heat stress, despite the use of a purpose-built ship following accepted procedures, reinforced the need for water and heat dissipation mechanisms to be followed (Ransley 2008; Stinson 2008). The animals which died were of the *Bos taurus* genotype. There were no losses in *Bos indicus* animals, supporting the higher heat tolerance of this genotype and its suitability to the live export trade going into the tropics in summer and with high heat load conditions on board.

Heat load and stress are major issues for cattle. Stinson (2008) reported that there were no mortalities in a heat stress event on board ship with *Bos indicus* genotypes; all losses occurred with *Bos taurus* genotypes coming from a winter to a hot tropical environment. *Bos indicus* cattle are well adapted to the tropical environment that they will experience in the destination country feedlots. Choosing the right genotype is very important, as is conditioning animals to the prevailing environmental conditions. That is why there are restrictions on the time of year for export from southern Australia to the northern hemisphere: if *Bos taurus* genotypes move quickly from a winter to a summer they have difficulty in adaptation. Accioly *et al.* (2003) compared the two genotypes and recorded a marked decline in food intake of the *Bos taurus* genotype as wet bulb temperature increased, but there was no change in intake by the *Bos indicus* genotype. The decline in food intake is a response to reduce heat production (from metabolism of food), an attempt to stop the rise in body temperature as a consequence of the inability to dissipate sufficient heat (metabolic energy or heat production). Inability to do so results in heat stress and, in severe cases, death. *Bos indicus* genotypes can dissipate more heat through evaporation than *Bos taurus* genotypes and so can cope with high temperatures and humidity (Kibler and Brody 1952; Frisch and Vercoe 1984). Maintaining a high level of food intake means that liveweight gain is maintained in the face of a high heat load but a decline in food intake means a reduced liveweight gain (or loss) of the *Bos taurus* genotype under these conditions. This means a loss in income to the shipping agent and problems with animal performance (and hence profitability) when they arrive in the feedlot at the destination country.

High temperatures and humidity can lead to acid balance and plasma electrolyte imbalances as a consequence of panting and respiratory alkalosis and increased sweating. There is increased loss of K and Na and it has been suggested that electrolyte addition might be beneficial (Beatty *et al.* 2007). This follows from the known effects of altering the dietary cation-anion difference (DCAD) of the diet, especially in dairy cow rations (McDonald *et al.* 2011). An electrolyte supplement was developed and used by Beatty *et al.* (2007) during a ship transport of *Bos taurus* cattle to the Middle East. Liveweight was increased by 2.9% over the experiment and urine pH increased by ~0.4 units, both results leading to a better production and welfare outcome (Beatty *et al.* 2007). Later experiments showed no effect from the electrolyte supplement, however, so the beneficial effects remain equivocal.

Early vessels were not built specifically for cattle but later vessels are purpose-built. A key difference has been ventilation to remove ammonia build-up and help in heat dissipation. Since 2004 vessels must meet specific requirements for ventilation and air changes. For example, on open decks there was previously no requirement for ventilation but there is now a requirement for it to be the same as closed decks (Schultz-Altmann 2008). Ventilation is based on height and so the required air changes range from 20–30/h for height changes from <1.8 to >2.3 m. Pines and Phillips (2011) document one such vessel which achieved, with reversible blowers, 60 air changes/h with some open and closed deck arrangements. Ammonia levels in excess of 25 ppm in the atmosphere are regarded as severely affecting animal welfare and are to be avoided (Phillips *et al.* 2010). This is the level set by Australian authorities for ship transport but Phillips *et al.* (2010) recommended a lower value of 19 ppm to avoid inflammatory responses in cattle. In the journey monitored by Pines and Phillips (2011) with sheep over a 12-day journey to the Middle East, there were occasions and positions on the ship where ammonia levels exceeded the 25 ppm limit. There were no instances when the level of hydrogen sulphide and carbon dioxide approached minimal limits set for human or animals, so these were not considered to be problems. Diets high in crude protein give rise to high levels of ammonia volatilisation from urea excreted in the urine. This is particularly so with lucerne pellets. Urine pH in cattle is normally around 7.9–8.0 and, if made acidic, volatilisation of ammonia decreases. Accioly *et al.* (2003) examined the effect of a pellet binding agent on urine pH. Using lime (a common binder) at 2% increased urine pH to 8.4 and replacing lime with gypsum reduced pH to 6.8, a value the authors did not consider low enough to reduce volatilisation of ammonia. Gypsum was a poorer binding agent. The addition of calcium chloride and ammonium chloride decreased urinary pH to 5.8–6.5 depending on diet and type of salt, in combination with binders of lime or gypsum. This was a very successful approach to decreasing atmospheric ammonia to below 25 ppm.

Density of cattle on board is regulated under the *Australian Standards for the Export of Livestock (Version 2.3) 2011* and *Australian Position Statement on the Export of Livestock (2011).* These ensure adequate space per animal and sufficient air movement to assist ventilation and evaporative heat loss. For example, for cattle the standards specify a minimum area of 1.11 m^2 per head for a 300 kg animal. Beatty *et al.* (2007) described pens of ~20.5 m^2 with 13 animals/pen. Cleaning of floors and pens occurs frequently (approximately every three days; Pines and Phillips 2011) and animal excrement is not allowed to drop onto lower decks.

Shy feeders and sick animals occur in feedlots within Australia – the phenomenon is not restricted to the shipping phase nor to the feedlot phase within the destination country. In land-based feedlots, these animals are more easily identified, isolated and given appropriate treatment. Shy feeders may result from an acidotic event with a learned aversion to the diet. More specific disease symptoms require the appropriate treatment. However, on board ship, established management procedures are more difficult to implement. Staff are now trained much better with new procedures providing training programs, a drug register, a registered stockman on all voyages and, in some cases, on-board veterinarians for long-haul voyages (mandatory requirement for voyages >15 days). It is more difficult to identify shy feeders on board because of the density of animals, and it is more difficult to move them to sick pens. Sea-sickness may affect certain animals and, while this may be episodic depending on the weather, its importance has not been clearly defined (C.J.C. Phillips, pers. comm.).

Vaccination at weaning has prepared animals for most disease challenges that they will face, e.g. tick-borne diseases. Trypanosomiasis is one problem facing live export cattle into Asia and there are a range of internal and external parasites which are preventable or treatable with appropriate chemo-prophylactic methods (Campbell 1989). There are standard operating procedures for cattle boarding a ship (DAFF 2011).

Animals destined for slaughter are not supposed to be pregnant, yet this occasionally occurs. Horned animals are not acceptable because of space requirements and welfare issues but may be allowed to travel if given extra space. Dehorning more mature animals to meet a specific requirement (if it exists) is not a suitable welfare outcome. These points really emphasise the need to select suitable animals for export. It has been noticed that incidents increase during times of short supply of suitable cattle (Farmer 2011).

As a consequence of the above research, feeding regimes, environmental conditions (especially ventilation) and responses to sick animals aboard ships can be managed well.

Post-shipping phase

Breeder cows

The majority of animals exported live are destined to grow out to a defined weight before slaughter. In some cases breeding animals (i.e. both pregnant heifers and cows) are exported for a particular program. The latter do not account for the large numbers involved in the live export trade and the numbers fluctuate depending on various government and commercial schemes to rapidly increase breeding cow numbers in a country. Many such initiatives have been made in the past, with very mixed success. The usual outcome is that the cows and heifers, usually pregnant on arrival, produce a calf and then only a very low percentage get another calf within a two- to three-year period. The main reason is usually related to the low body condition score (BCS) of the cow after calving, due to inadequate nutrition. It seems an anachronism that after 50 years of failed schemes they are still promoted today without any support for the farmers who take on these animals, to meet some government objective or commercial imperative. Better companies involved in this trade sometimes offer a supplementary feeding regime to farmers for a six- to 12-month period, which helps maintain BCS and so a much higher percentage of cows return to oestrus within the first 12 months. However, without a continuing better feeding regime these cows drop in BCS in the subsequent lactation, and reproduction rates inevitably decline to low levels. Such schemes need better management of the cow. The Integrated Village Management Scheme (Poppi *et al.* 2011) provides one way in which this can be achieved. It uses the principles developed in the cow–calf systems of northern Australia to enable a cow–calf system to operate with high reproduction rates in these environments. The key principles are to wean early (three to six months) and reduce the nutrient requirement of the cow, thus saving BCS, have an effective artificial insemination or natural mating scheme, preferentially feed the weaned calf better forages and preferentially feed the cow better forages at least during early lactation. This means that a cow can maintain weight on low-quality feed without a large cost for the bulk of the year, so it is simply managing the resources better to suit the class of animal. This system has led to high reproduction rates (80% of first lactation cows and 90% of mature cows pregnant within mating period) (Poppi *et al.* 2011).

Animals for slaughter

The majority of animals are destined for slaughter. Unlike the sheep trade, most if not all cattle are grown out (fattened) in the destination country and not usually slaughtered on entry. There are some exceptions. Fattening is a term used in Asia to indicate growth to achieve slaughter specifications, whereas in Australia it more specifically designates the last period of growth as an animal reaches a target weight for slaughter, usually approaching its mature size, and hence it is mainly depositing fat. Australian boxed beef export markets usually require a carcass weight of 180–420 kg (Fig. 12.1) with a defined level of fat at a certain age. The latter is associated with eating qualities of the meat and cultural preference for a level of fat or marbling. Cattle involved in the live export trade are different in that the local wet market usually requires a lean product and there is much less emphasis on having a defined fat cover. Many of the feedlots within these countries are a partnership between large Australian pastoral companies or consortia and local businesses.

The destination of animals for slaughter depends on government policy. In some countries a proportion of the animals are required to go to smallholders, who may fatten one to five animals, or to small feedlotters with

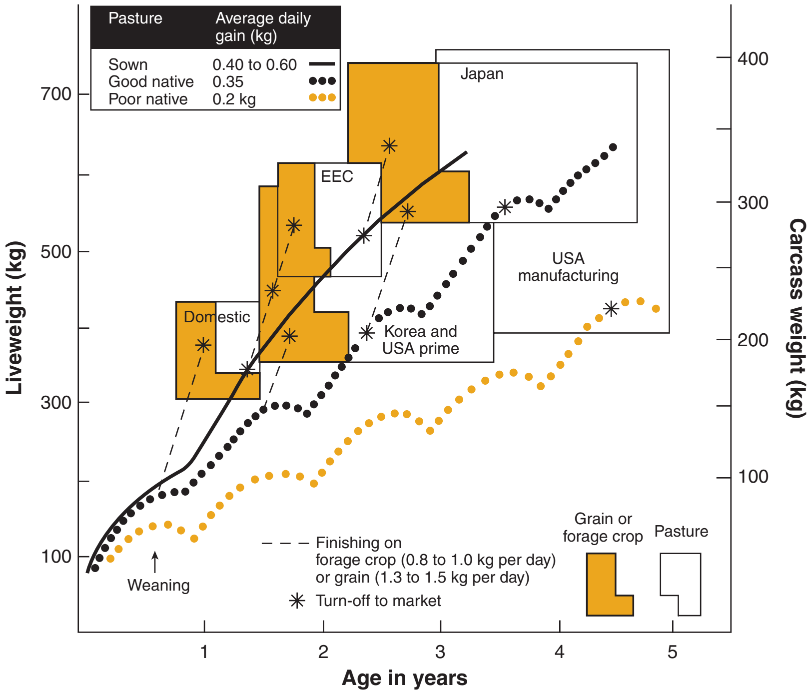


Figure 12.1: Growth patterns of beef cattle on different pastures and the finishing options for various markets. Source: Reproduced with permission (Gramshaw and Lloyd 1993).

numbers up to ~10–50 animals The bulk, if not all, of the animals will go into large-scale feedlots similar to an Australian feedlot. A major issue is the ability of animals to adjust to a smallholder operation. Australian cattle that have been exported have usually been handled on only two occasions before export (weaning and final muster), then had intensive handling associated with the stressful events of transport, holding, shipping and final unloading. The initial behaviour can be a problem for the farmer, hence well-behaved, easily handled animals are valued. This is a matter of selection of animals for breeding within Australia (e.g. selection on flight speed) and on the training process at weaning. *Bos indicus* cattle quieten very quickly and even weaners which have rarely been handled by humans will in a matter of days be led and rubbed without any problems and will even approach, stand and nuzzle the human who is providing feed.

Feeding the animal

Cattle fattening in the Asian countries is based largely on crop residues whereas in Australia it is based largely on grain. The crop residues can vary in quality and ration formulation is important. The smallholder feeds according to supply and cost of by-products without regard to feed formulation, in contrast to large commercial feedlots, and as a consequence growth rates can be very low. In a recent survey in Indonesia, the Straw Cow project found that Ongole and European cross (Limousin or Simmental *x* Ongole) only grew at rates of 0.1 kg/ and 0.4 kg/d respectively and that the ration consisted of 48–78% rice straw plus green grass and tree legumes with some by-products of rice bran or cassava (Hanifah *et al.* 2010; Pamungkas *et al.* 2012). In the same project, a simple village diet based on Onggok, copra meal, palm kernel cake and elephant grass resulted in a liveweight gain of 1.1 kg/d in Ongole bulls (T.M. Syahniar, pers. comm.). In large commercial feedlots, nutritionists formulate rations according to least-cost formulations and obtain growth rates of Brahman cattle similar to those achieved in an Australian feedlot (~1.5 kg/d). These feedlots use a lot of maize (corn) silage, usually subcontracted from local small farmers and cut at specified stage of growth (milky dough) according to the best principles of the manufacture of maize silage. Other high-energy ingredients are cassava and various by-products (e.g. Onggok from tapioca), fermented soybean waste, rice bran, copra meal, palm kernel cake, elephant grass, pineapple pulp, tomato pulp and molasses (Ffoulkes 2012). There are many other ingredients and in reality people take advantage of what is available as it is often seasonal (Fig. 12.2). This creates problems

Figure 12.2: Weaned cattle fed elephant grass in a cut-and-carry system on a smallholder farm in Lampung, Indonesia. Source: D. Mayberry.

of formulation, but the larger companies can forward contract and store various by-products. This luxury is not available to the smallholder, who must use what is available in that season. Often, smallholder farmers band together to hire a vehicle and travel to another district to buy food for their cattle. The daily operation is usually a cut-and-carry system so for the smallholder there is a significant daily time involved in gathering adequate feed, from one to six hours a day depending on season and access to fields (Poppi *et al.* 2011). Large commercial feedlots have a large workforce or subcontract small farmers to provide feed daily. Small trucks loaded with freshly cut maize ready for ensilage are seen each day, in season, lined up ready for entry into the feedlot complex. Such a system provides a viable alternative for these farmers to get income and creates employment for a large number of people. These social implications should not be ignored when looking at large feedlots and their operation. Of course in some countries and systems the whole operation, including ownership of the land, crops and by-products, belongs to the one company which is value-adding a product. An example is the use of pineapple pulp and tomato pulp in certain countries, the residue from juice extraction or canning industries all owned and operated by large companies.

Animal health

Health of animals can be an issue but if cut-and-carry systems are used by smallholders or silage by a feedlot then issues associated with internal parasites are low. Other parasites and viral and bacterial infections vary with country and epidemiology of the specific organism such as brucellosis, botulism, bovine ephemeral fever and tick-borne diseases. A strict protocol is followed for entry of livestock into the destination country. Most of the health checks are carried out before boarding the ship but some are instigated by the large feedlots on entry. Smallholders are usually averse to spending money on the health of animals and rely on government extension services to provide medication. This can be intermittent.

MLA has published a manual for South-East Asian feedlots and offers other technical assistance materials (MLA 2010, 2011a,b, 2012b). These outline best practice induction, handling, management and nutrition of live export cattle on arrival in the country and movement into a feedlot.

CONCLUSION

The live export trade has underpinned the large developments in beef cattle in northern Australia in recent years. It has provided an alternate market to the southern Australian processing plants including those close to Brisbane, and so achieved higher prices and lower costs for cattle producers in the north of Australia. This has meant the development of better grazing management strategies and land condition as a profitable enterprise enables producers to undertake such strategies. There are many groups involved in the trade, supporting the transport, feeding, health and supervision of animals. It is a volatile market with intermittent large changes in access to key markets. At present, Indonesia is the main market for cattle from northern Australia.

There are regulations relating to selection, husbandry and transport of animals to port of departure, transport at sea and traceability of animals to point of slaughter within the importing country. There are also standard operating procedures and training manuals for people involved in the trade. There are ethical and welfare issues which face the trade: it is doubtful that all parties will ever be satisfied and some recognised welfare groups are completely opposed to live export in any form. Despite this, the industry has moved to address the welfare issues and has recognised and accepted the need to implement the highest welfare standards. These efforts are underpinned by the Australian government's regulatory requirements for exporters (the Exporter Supply Chain Assurance System) regarding the export of feeder and slaughter livestock.

Research has addressed the feeding and husbandry of animals before, during and post-shipping transport.

Significant advances have been made in this area. In particular, diet formulation has achieved lower ammonia loads and better feeding and health of animals. Better ship and pen designs for ventilation have improved air quality and evaporative heat dissipation. The training and management of animals on properties follow well-accepted principles which result in settled cattle under transport within Australia as well as on board ship.

REFERENCES

Accioly JM, Beatty DT, Barnes AL, Pethick DW, Taylor EG, Tudor GD, White CL, Maloney SK, McCarthy MR, Pluske JR, Costa ND (2003) Nutrition during live export of cattle. *Recent Advances in Animal Nutrition in Australia* **14**, 49–56.

Alliance Consulting and Management (2001) Influence of pre-delivery management on livestock performance: desk top study. Report for Meat and Livestock Australia/Livecorp. Live.104A.

Beatty DT, Barnes A, Taplin R, McCarthy M, Maloney SK (2007) Electrolyte supplementation of live export cattle to the Middle East. *Australian Journal of Experimental Agriculture* **47**, 119–124. doi:10.1071/EA06041.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005a The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management. *Australian Journal of Experimental Agriculture* **45**, 1075–1091. doi:10.1071/EA03097.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005b The northern Australian beef industry, a snapshot. 3. Annual liveweight gains from pasture based systems. *Australian Journal of Experimental Agriculture* **45**, 1093–1108. doi:10.1071/EA03098.

Bowen J (1995) *Kidman: The Forgotten King*. Angus and Robertson, Sydney.

Campbell RSF (1989) Future challenges of disease in the beef cattle industry. *Australian Veterinary Journal* **66**, 252–257. doi:10.1111/j.1751-0813.1989.tb13583.x.

CIE (2011) The contribution of the Australian live export industry. Centre for International Economics, Canberra.

DAFF (2011) *Australian Standards for the Export of Livestock 2011* (Version 2.3) and *Australian Position Statement on the Export of Livestock 2011*. Department of Agriculture, Fisheries and Forestry. <http:/www.daff.gov.au/livestock exportstandards>.

DAFF (2012) *Exporter Supply Chain Assurance System*. Department of Agriculture, Fisheries and Forestry. <http://www.daff.gov.au/aqis/export/live-animals/livestock/escas>.

Daly RA (1960) The early days. In *Cattle Country*. (Eds F O'Loughlin and FH Johnston) pp. 64–69. F.H. Johnston Publishing, Sydney.

Durack M (1983) *Sons in the Saddle*. Constable, London.

Farmer W (2011) Independent review of Australia's live export trade. Commonwealth of Australia.

Ffoulkes D (2012) *Feeding Australian Commercial Cattle in South East Asia*. Technical brochure. Department of Resources, NT Government. <http://www.nt.gov.au/d/Primary_Industry/Content/File/feeding_aust_comm_cattle_sea.pdf>.

Frisch JE, Vercoe JE (1984) An analysis of growth of different cattle genotypes reared in different environments. *Journal of Agricultural Science, Cambridge* **103**, 137–153. doi:10.1017/S0021859600043409.

Gramshaw D, Lloyd D (1993) *Grazing the North: Creating Wealth and Sustaining the Land*. © State of Queensland, Department of Primary Industries.

Hanifah VW, Priyanti A, Mahendri IGAP, Cramb RA (2010) A comparison of feeding management practices of beef cattle smallholders in lowland and upland sites in East Java. In *Proceedings of the 5th International Seminar on Tropical Animal Production, Community Empowerment and Tropical Animal Industry*, Yogyakarta, Indonesia, pp. 189–195.

Hunt LP, Petty S, Cowley R, Fisher A, Ash AJ, MacDonald N (2007) Factors affecting the management of cattle grazing distribution in northern Australia: preliminary observations on the effect of paddock size and water points. *Rangeland Journal* **29**, 169–179. doi:10.1071/RJ07029.

Hunter RA, Day A, Blakely SK (2002) Role of high molasses diets in the live exports supply chain. *Animal Production in Australia* **24**, 109–112.

Jones RJ (1990) Nitrogen rate and stocking rate effects on steer gains from grazed irrigated pangola grass in the Ord valley, Western Australia. *Australian Journal of Experimental Agriculture* **30**, 599–605. doi:10.1071/EA9900599.

Kibler HH, Brody S (1952) XIX. Relative efficiency of surface evaporative, respiratory evaporative, and non-evaporative cooling in relation to heat production in Jersey, Holstein, Brown Swiss and Brahman cattle, 5° to 105°F. Research Bulletin No. 497. University of Missouri Agricultural Experiment Station.

LiveLink (2011) Australian livestock export statistical review 2010/2011 Meat and Livestock Australia, Sydney.

McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA, Sinclair LA, Wilkinson RG (2011) *Animal Nutrition*. 7th edn. Benjamin Cummings, UK.

McLennan SR, Poppi DP (2011) Recent advances in nutrition for improving liveweight gain. *Proceedings of the Northern Beef Research Update Conference*, Darwin, pp. 94–101.

MLA (2007) *Is it Fit to Export?* Meat and Livestock Australia, Sydney.

MLA (2008) *Tips and Tools: Livestock Export Program. Preparation of Cattle for Live Export*. Meat and Livestock Australia, Sydney.

MLA (2010) *South East Asian Feedlot Manual*. Meat and Livestock Australia, Sydney.

MLA (2011a) *Standard Operating Procedures for the Welfare of Cattle in Overseas Markets*. Meat and Livestock Australia, Sydney.

MLA (2011b) *Tropical Beef Production*. Meat and Livestock Australia, Sydney.

MLA (2012a) *Statistical Review July 2011–June 2012*. (Ed. R Uchida). Meat and Livestock Australia, Sydney.

MLA (2012b) *MLA Training Manual* (in press). Meat and Livestock Australia, Sydney.

Morey (2011) The Indonesian cattle and beef industries. Morelink (unpublished).

O'Reagain P, Bushell J, Holmes B (2011) Managing for rainfall variability: long-term profitability of different grazing strategies in a northern Australian tropical savannah. *Animal Production Science* **51**, 210–224. doi:10.1071/AN10106.

OIE (2011a) *World Organisation for Animal Health: International Standards*. <http://www.oie.int/international-standard-setting/overview/>.

OIE (2011b) *The OIE's Achievements in Animal Welfare*. <http://www.oie.int/animal-welfare/animal-welfare-key-themes/>.

OIE (2011c) *Transport of Animals by Sea*. <http://www.oie.int/index.php?id=169&L=0&htmfile=chapitre_1.7.2.htm>.

Pamungkas D, Antari R, Mayberry DE, Poppi DP (2012) A growth comparison of Ongole and European cross cattle kept by smallholder farmers in Indonesia. In *Proceedings of the 15th Asian Australasian Animal Production (AAAP) Congress*, Bangkok, Thailand (in press).

Petherick JC (2005) Animal welfare issues associated with extensive livestock production: the northern Australian beef cattle industry. *Applied Animal Behaviour Science* **92**, 211–234. doi:10.1016/j.applanim.2005.05.009.

Petty SR, Poppi DP, Triglone T (1998) Effect of maize supplementation, seasonal temperatures and humidity on the liveweight gain of steers grazing irrigated *Leucaena leucocephala/Digitaria eriantha* pastures in north-west Australia. *Journal of Agricultural Science, Cambridge* **130**, 95–105. doi:10.1017/S0021859697004966.

Petty SR, Hunt L, Cowley R, McDonald N, Fisher A (2012) *A Guide to Intensive Development of Cattle Stations in Northern Australia*. (Ed. I Partridge). Meat and Livestock Australia, Sydney.

Phillips CJC (2005) Ethical perspectives of the Australian live export trade. *Australian Veterinary Journal* **83**, 558–562. doi:10.1111/j.1751-0813.2005.tb13336.x.

Phillips CJC, Pines MK, Latter M, Muller T, Petherick JC, Norman ST, Gaughan JB (2010) The physiological and behavioural responses of steers to gaseous ammonia in simulated long-distance transport by ship. *Journal of Animal Science* **88**, 3579–3589. doi:10.2527/jas.2010-3089.

Pines MK, Phillips CJC (2011) Accumulation of ammonia and other potentially noxious gases on live export shipments from Australia to the Middle East. *Journal of Environmental Monitoring* **13**, 2798–2807. doi:10.1039/c1em10425j.

Pingali P (2006) Westernization of Asian diets and the transformation of food systems: implications for research and policy. *Food Policy* **32**, 281–298. doi:10.1016/j.foodpol.2006.08.001.

Poppi DP, Fordyce G, Panjaitan T, Dahlanuddin, Quigley SP (2011) Case study 2: developing an integrated production system for Bali cattle in the eastern islands of Indonesia. In *Beef Production in Crop-livestock Systems: Simple Approaches for Complex Problems*. (Ed W Winter). ACIAR Monograph No. 145. Australian Centre for International Agricultural Research, Canberra.

Queensland Government. *Livestock Export from Queensland*. Queensland Government Fact Sheet. <http://www.dpi.qld.gov.au>.

Ransley RM (2008) Competencies, education and training in the international transportation industry: sea transport. *Veterinaria Italiana* **44**, 263–272.

Rose L (1960) Australia's top half. In *Cattle Country*. (Eds F O'Loughlin and FH Johnston) pp. 109–140. F.H. Johnston Publishing, Sydney.

Schultz-Altmann AGT (2008) Engineering and design of vessels for sea transport of animals: the Australian design regulations for livestock carriers. *Veterinaria Italiana* **44**, 247–258.

Schutt KM, Burrow HM, Thompson JM, Bindon BM (2009) Brahman and Brahman crossbred cattle grown on pasture and in feedlots in subtropical and temperate Australia. 2. Meat quality and palatability. *Animal Production Science* **49**, 439–451. doi:10.1071/EA08082.

Scoones I, Bishi A, Mapitse N, Moerane R, Penrith ML, Sibanda R, Thomson G, Wolmer W (2010) Foot-and-mouth disease and market access: challenges for the beef industry in southern Africa. *Pastoralism* **1**, 135–164.

Stinson PR (2008) Two incidents that changed quality management in the Australian livestock export industry. *Veterinaria Italiana* **44**, 177–186.

Streeter S (2012) Identification of causal factors affecting liveweight gain in Northern Territory cattle herds. B.NBP 0390 Final Report. Meat and Livestock Australia, Sydney.

Swanson JC, Morrow-Tesch J (2001) Cattle transport: historical, research and future perspectives. *Journal of Animal Science* **79,** (E Supplement), E102–E109.

Thompson T, Martin P (2012) *Australian Beef: Financial Performance of Beef Cattle Producing Farms, 2009–10 to 2011–12*. <http://www.daff.gov.au/abares/publications>.

Tyler R, English B, Sullivan M, Jackson D, Matthews R, Holmes W, MacDonald N, Oxley T, Leigo S, Smith P (2012) *Weaner Management in Northern Beef Herds*. Meat and Livestock Australia, Sydney.

Wythes JR, McLennan SR, Toleman MA (1980) Liveweight loss and recovery in steers fasted for periods of twelve to seventy two hours. *Australian Journal of Experimental Agriculture and Animal Husbandry* **20**, 517–521. doi:10.1071/EA9800517.

Wythes JR, Arthur RJ, Thompson PJM, Williams GE, Bond JH (1981) Effect of transporting cattle various distances on liveweight, carcase traits and muscle pH. *Australian Journal of Experimental Agriculture and Animal Husbandry* **21**, 557–561. doi:10.1071/EA9810557.

Wythes JR, Kaus RK, Neman GA (1985a) Bruising in beef cattle slaughtered at an abattoir in southern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **25**, 727–733. doi:10.1071/EA9850727.

Wythes JR, Johnston GN, Beaman N, O'Rourke PK (1985b) Preslaughter handling of cattle: the availability of water during the lairage period. *Australian Veterinary Journal* **62**, 163–165. doi:10.1111/j.1751-0813.1985.tb07279.x.

This page intentionally left blank

13 Biosecurity and beef cattle health, husbandry and welfare

M. Laurence

INTRODUCTION

This chapter is an overview of biosecurity in Australia as applied in beef cattle production. It covers protocols, notifiable diseases and risk assessment, and provides details of the resources needed to establish a sound, on-farm biosecurity protocol.

The chapter also gives a summary of the beef cattle diseases that most affect productivity of cattle in Australia. This summary is not intended as a substitute for a veterinary textbook, but rather as a reference for tertiary students, producers, animal and agricultural scientists, farm consultants and veterinarians. Animal health is put into the context of the whole production system, emphasising understanding of the presentation and significance of cattle disease, prevention and treatment.

A section at the end of the chapter covers basic cattle husbandry and handling. It describes some less traditional methods of handling and managing cattle as they might be applied in the context of Australian cattle production systems, highlighting the advantages of low-stress techniques. The chapter includes references for further reading, but does not purport to be a comprehensive review of this complex and ever-changing field of animal husbandry.

BIOSECURITY

Strict customs and quarantine laws guard Australia's agricultural enterprises, and ensure access to valuable agricultural export markets. The principle of biosecurity underpins this protection from animal or plant disease and pests. Biosecurity is broadly defined as the measures taken to protect agriculture and animal production from pests and diseases, but different stakeholders have different definitions for the term. The most appropriate definition for this book is supplied by the Department of Agriculture, namely 'Biosecurity is protecting the economy, environment and people's health from pests and disease. It includes trying to prevent new pests and diseases from arriving, and helping to control outbreaks when they do occur'. In this chapter the focus is on farm biosecurity, which refers to all risk-factor assessments, principles and management decisions that keep the farm's animals free of disease.

Farm biosecurity

Farm biosecurity is achieved by bioexclusion and biocontainment. Bioexclusion refers to farm management that keeps pathogens out, such as boundary fences or washdown facilities at the farm entrance. Biocontainment refers to management that contains pathogens within the farm. Vaccination, segregating stock of different age groups, and using 'all-in all-out' systems are examples of biocontainment measures. Bioexclusion measures are always imperfect, so biocontainment is important to limit the spread of unwanted pathogens within the farm, or to neighbouring farms.

If a farm is to have proper biosecurity, it needs a biosecurity plan which considers the risks to be assessed and addressed, and includes strategies to manage disease (Dargatz 2002). Producers do not always instigate rigorous biosecurity plans and protocols, possibly because the process takes time, can be expensive and does not directly generate income. Many producers consider that developing biosecurity protocols is unnecessarily complicated, or that they already do the most critical things suggested by biosecurity advisers.

The key to improving farm biosecurity is to relate good biosecurity directly to improved productivity and profitability of the farm. For instance:

- all producers know that bad things happen, but the probability of the misfortune can be reduced through good practices. Use of practical examples to describe the concepts of risk-management to producers can show the benefits of preventative actions;
- all the advantages of these actions must be explained, and shown to outweigh the costs and any disadvantages. Cost-effectiveness is clearly demonstrated using case studies of the financial consequences for producers following a biosecurity breach;
- producers can be shown how to superimpose a formal biosecurity plan upon their current farm practices, cutting to a minimum the cost of implementing an effective biosecurity system;
- the planning process must be logical, practicable and easily understood.

In the absence of disease, a biosecurity plan is a form of insurance. Its cost must be weighed against the risk of a breach. Others have reviewed biosecurity on beef farms and have supplied practical tips on implementation of biosecurity plans and strategies (DAFWA 2002; Dargatz 2002; AHA 2003a, b; Larson 2008; Turner 2011). Information in those publications will augment the content of this chapter.

Risk pathways for livestock enterprises

Pathogens can enter a livestock enterprise in various ways, described as biosecurity risk entry pathways (Table 13.1). It is important that producers have a good understanding of these pathways in order to apply protocols that minimise risk.

Principles of risk-management

There are six basic principles of managing biosecurity risks. These principles can be applied pre-entry, at the point of entry to a farm and post-entry.

Barriers

Barriers can be physical, such as fences, or procedural, such as having specific protocols for the introduction or induction of new livestock on to a farm. Boundary fences in particular must be well maintained and suitable for the livestock both on the farm and on the neighbouring farms. Signs at the front gate should clearly describe what biosecurity protocols are in place on the farm. Signs should include homestead or mobile telephone numbers or VHF channel frequencies so visitors can easily contact producers without having to enter the property. There should be vehicle wheel dips, regularly filled with appropriate disinfectant, at front gates. Ideally there would also be a washdown bay at the front gate for removal of mud, dust and animal waste from the wheels and inside of trucks. Entrance roads should be well fenced so that visitors are restricted as to what they can access and the producer has control over all visitor vehicle movement.

Resistance

Increasing the resistance of the herd to disease is a very useful biosecurity technique. This is usually a post-entry procedure and is done using basic husbandry practices like appropriate vaccination of all animals, and good nutrition so that animals are not stressed and therefore immuno-compromised and susceptible to disease. Parasites must be well controlled at induction on to the farm and then at regular intervals during the life of the animals. Paddocks need to be managed to minimise parasite burdens and the risk of re-infection of animals. Low-stress handling and appropriate handling facilities all contribute to decreasing the stress load on animals and this has obvious health benefits.

Introductions

New staff should be well trained and have a good understanding of animal handling and biosecurity. Providing staff with a simple biosecurity manual is one easy way of mitigating the risks associated with new people. Day to day, visitors should adhere strictly to biosecurity protocols. There should be only one entry point to the farm, designated visitor parking and signage so visitors know what is expected of them before they enter the property. A good idea is a sign-in book that asks some basic questions about previous exposure to livestock and that means the owner always knows who is on the property. Visitors should always wear clean clothes and have washed their hands and boots before coming on to the property.

Where feasible, new stock should be purchased only from reputable, biosecurity-conscious suppliers with National Vendor Declarations (NVD) and Waybills. The NVD is the main document that helps to underpin

Table 13.1: Biosecurity risk entry pathways for a livestock enterprise

Route	Risk explanation
Family and friends	Must not be considered low-risk
Visitors	May have been in contact with infected livestock in Australia or overseas
Farm staff	May keep livestock and other animals at home
Livestock agents	Highly likely to have been in contact with livestock
Tradesmen and mustering contractors	Highly likely to have been in contact with livestock
Animal	
Introduced livestock	May carry disease acquired at farm of origin, at the market or during transit from contacting infected animals or contaminated equipment
Neighbouring livestock and other animals	Contact through permeable fences, wind-borne aerosol spread over short distances, co-mingling of stray stock
Wild birds	Wild birds can carry or transmit viruses to feed, water or cattle holding areas
Sick and dead livestock	May be a source of disease
Wild animals	Includes dogs, cats, marsupials, feral pigs
Rodents	Rodents can carry or transmit pathogens to feed, water or stock holding areas
Pets	Pets that move freely in and out of farm area can carry disease
Flies and other insects	Flies and other insects may carry pathogens
Inorganic	
Borrowed farm equipment	Farm equipment can be heavily contaminated with organic material such as dirt, manure and plant material
Market equipment such as trailers, prodders, flappers	Equipment returning from saleyards, abattoirs, markets is a high risk
Vehicles including motorbikes, farm utility vehicles, stock transport trucks including knackery trucks	Lower risk but large amounts of organic material can be carried on wheels and in wheel wells
Organic	
Surface water	Dams, ponds, channels, swamps, creeks, rivers, lakes may be contaminated by viruses and bacteria from neighbouring or upstream cattle and other species
Farm manure	Moisture, spilt and uneaten feeds and organic material may be attractive to flies, birds, rodents, deer etc. that can carry disease
Introduced feed	Non-processed feeds carry greater risk of virus and bacterial contamination
Contaminated feed	Opened bags in non-scavenger-proof storage are high-risk as are unprocessed feeds because, unlike pellets, they have not been heat-treated and stored

Source: Adapted from Jubb (2008).

Australia's excellent meat and livestock food safety reputation. Meat and Livestock Australia's Livestock Production Assurance (LPA) program uses the NVD/Waybill to trace livestock movement. Important information regarding livestock history is transferred through the supply chain to the end consumer so that they can be assured of the safety and quality of their red meat.

Every effort should be made to assess the health of animals before they are purchased and certainly before they arrive on the property. Certification of vaccination, supplementation and parasite control history are very useful in managing the risks associated with buying animals. It is not always possible to get these, particularly when buying animals out of saleyards. In these circumstances, careful induction and quarantine of new animals is vital. New animals should not be mixed for at least two weeks with animals already on the farm. That includes preventing nose-to nose-contact through a fenceline or yard.

Dimensions

When risk controls are being planned and implemented, advantage should be taken of time, distance and gravity to enhance biosecurity.

'Time' is associated with periods of quarantine. The principle is that a quarantine period may allow the numbers of pathogens to decline over time.

'Distance' allows for the separation of things such as farms, sheds or age groups of animals. Separating sources of pathogens is often more effective with increasing distance.

'Gravity' reduces exposure of livestock grazing on high ground or housed in sheds to pathogens that might be carried into herds and flocks by movement of water or soil.

Load

A pathogen load always exists on a farm. Minimising that load is an important aspect of management, and an 'all-in all-out' system makes that management easier. In other words, any group of animals is treated as a distinct unit, and is not mixed with any other group at any time or for any reason, whether in the induction phase on to the farm, for the duration of the group's life on the farm, or when the group is taken away from the farm. Controlling the pathogen load starts as soon as any group of animals arrives on the farm, with the application of good hygiene and sanitation practices (e.g. composting/disposal of quarantine pen faeces and bedding), good vaccination protocols, immediate identification and isolation for treatment of sick animals, and removal of dead animals.

Monitoring

This is a key step in managing biosecurity risk. The early detection of disease and pathogens is the best way to minimise pathogen build-up on the farm and to contain the spread of disease. Daily checks of animals, particularly if they are intensively farmed, are vital. Sick animals should be immediately removed, isolated and treated in hospital pens and if a contagious disease is suspected then the herd or mob of origin should be quarantined until no more cases are detected. Veterinary advice on how best to treat and manage sick animals should be sought.

The farm biosecurity plan

When considering the development of a farm biosecurity plan, it is important to note that farms with few biosecurity inputs can substantially increase biosecurity for little cost. In contrast, farms with high biosecurity inputs can usually only further improve biosecurity at high cost. The efficacy of certain controls applied in isolation may be low, but very high when those controls are implemented in combination with other controls of low efficacy. Biosecurity risk-controls are often multi-purpose, providing other value to the farm. Before finalising a farm plan it is important to be realistic about what can actually be achieved. Control measures can be evaluated according to such criteria as:

- practicality – how practical is it?
- effectiveness – how effective is it?
- cost – can the producer afford it and is the enterprise sufficiently profitable to absorb the cost? Is there sufficient cash flow?
- competency – do the producer and farm staff have the skills, knowledge, experience and confidence to implement the control measure?
- sustainability – all of the above considered, is this control measure sustainable over time?

A comprehensive library of biosecurity risk controls for a beef farm (Table 13.2) and an assessment of their effectiveness should be consulted when designing a farm plan.

Decontamination and disinfection

Some generalisations about controlling livestock pathogens include:

- most pathogens persist in the live host until the host's immune system eliminates the pathogen or the host dies;
- once the host dies, most pathogens also soon die;
- pathogens in oral or nasal secretions or excreted by the animals in faeces will survive for a period in the environment and serve as a source of infection for other animals;
- the period that pathogens will survive in the environment depends on the amount of moisture, sunlight, heat and acidity they are exposed to;
- heat, dryness and sunlight can all be used to help disinfect objects or areas of soil. A hot, dry, sunny day will rapidly inactivate many pathogens, whereas cold, damp, overcast conditions will encourage their persistence;
- microorganisms tend to survive longer in dark, moist, cool conditions;
- a mix of detergents and water is effective in killing many pathogens;
- detergents and disinfectants injure and kill pathogens through their ability to denature the cell wall or enter the cell and damage protein and enzymes, or both;
- scrubbing with detergents and water dilutes the numbers of pathogens to low levels that are less likely to cause infection;

Table 13.2: A library of biosecurity risk controls of a beef farm

Control category	Risk control	Effectiveness
Limit visitor access to the farm	Minimise the number of entrances to the property	High
	Post signs at the farm entrance; identify the farm as a biosecure area and inform visitors of procedures and requirement to follow the farm's biosecurity rules	High
	Establish a visitors' parking area away from areas where animals might graze or be held	High
	Place animal delivery and load-out facilities on the perimeter of the farm	High
	Lock gates	High
	Restrict farm access for visitors who have travelled to certain international areas where they may have had contact with potentially infectious animals for 10 days	High
	Restrict access to the farm for high-risk people who may have had contact with animals, e.g. neighbours, stock and station agents, feed salesmen, artificial insemination technicians and veterinarians, and utility services contractors	High
Ensure vehicles are cleaned and disinfected	Establish washdown points for vehicles and equipment	High
	Install wheel baths with disinfectant	Low
	Ensure stock transport vehicles are cleaned before loading animals coming to the farm. Trucks and other vehicles entering the property should not have visible manure and mud	High
	Insist that feed delivery trucks have not previously carried meat and bone meal	High
Minimise vehicle traffic	Keep a separate vehicle just for use on the farm	High
	Prevent off-farm vehicles from driving in areas where animals travel	High
Establish farm in low-risk location	Locate the farm/herd in an isolated area	Moderate
	Locate the farm/herd on an elevated area afforded some protection by gravity	Moderate
	Locate the farm/herd upstream of other farms	Moderate
	Plant windbreaks around the farm perimeter to break up wind-flow	Moderate
Fence off high-risk areas	Minimise fenceline contact with neighbouring animals by erecting suitable barriers or establishing suitable buffer areas	High
	Regularly inspect and maintain fences to keep the farm's animals in and others out	High
	Fence off creek and river waters potentially contaminated by faeces from neighbouring or upstream herds and stray or wild animals	High
Use quarantine and isolation	Maintain a closed herd	High
	Quarantine all new animals or animals that have been taken off the farm and then brought back, such as bulls and show animals. For 10 days	High
Source introductions from low-risk herds	Prevent direct and indirect contact of cattle with other cattle at shows	High
	Buy cattle from quality-assured farms and herds with a biosecurity plan. Require disease testing, vaccination records and health certification (i.e. know the health history of incoming animals). Examine the production records of the source herd for signs indicative of disease. Don't buy at saleyards	High
Segregate livestock by age	Graze susceptible younger stock on the higher ground or near the centre of the property, or both	Moderate
	Do not place cattle of different ages in the same paddock or stockyard pen	Moderate
	Work from younger or healthier animals to older higher-risk animals	Moderate
Manage sick and dead animals	Isolate all sick animals, preferably for two weeks after symptoms of illness have stopped; designate a hospital pen or paddock	Moderate
	Promptly euthanase animals that are not going to recover	Moderate
	Promptly remove and dispose of dead animals	Moderate
Control visitors	Provide visitors with clean boots and clothes or coveralls	High
	Install footbaths	Low
	Do not let visitors step into feed troughs or wash in water troughs	High
	Limit contact by visitors with the herd	High

(*Continued*)

Table 13.2: (*Continued*)

Control category	Risk control	Effectiveness
Suppress other animals	Prevent pets from straying into cattle grazing areas	High
	Do not allow visitors to bring farm dogs or other animals on to the property unnecessarily	High
	Do not let dogs, birds or other animals have access to dead livestock	High
	Control flies, mosquitoes, rodents, foxes, scavenging birds and other vermin	High
Clean and disinfect extra-farm fomites	Minimise exposure of farm staff to cattle outside the herd	High
	Wear clean clothing and boots when working around animals	High
	Ensure veterinarians' and stock and station agents' equipment is disinfected before it is used on the farm	High
	Clean and disinfect farm equipment shared with other livestock owners	High
	Buy equipment, to avoid borrowing from other producers	High
Clean and disinfect intra-farm fomites	Clean equipment and boots and change clothing between animal groups with different health status	Moderate
	Clean and disinfect all shared equipment between different groups of animals	Moderate
	Disinfect animal husbandry equipment between animals – includes dehorners, castration knives	Moderate
	Do not use the same loader for feed and manure hauling, or properly clean and disinfect between uses	Moderate
Monitor the health of the herd	Educate owners, managers and employees to recognise and report diseases	High
	Keep records of all disease occurrences and treatments	High
	Maintain a written biosecurity plan and update it regularly	High
	Individually identify every animal and keep movement records if animals are moved between farms	High
	Monitor and inspect animals daily for signs of illness	High
	Have a veterinarian necropsy animals that die from unknown causes	High
	Routinely sample the herd and the environment for pathogens	High
Monitor and protect feed and water supplies	Monitor water quality and ensure upstream contamination by other animals is not occurring	Moderate
	Protect stored feed; lock feed storage sheds	High
Source only quality assured feedstuffs and biological products	Source only quality-assured feed from reputable vendors	High
	Source only quality-assured feed supplements and additives from reputable vendors	High
Increase the resistance of the herd to disease	Vaccinate the herd against endemic diseases	Moderate
	Use low-stress management practices during movement and processing	Moderate
	Prevent overcrowding	Moderate
	Prevent inbreeding	Moderate
	Ensure proper nutrition	Moderate

Source: Adapted from Jubb (2008).

- the dilution effect serves to reduce the number of pathogens to less than the infective dose;
- some pathogens are very tough and require a two-phase approach to kill them. The first phase uses detergents to remove organic matter that might protect pathogens, to kill pathogens by the direct action of detergents on the cell wall of the pathogen, and to dilute pathogens when combined with water and scrubbing. The second phase uses disinfectants such as chlorine that are more effective after detergents have removed organic matter and exposed and diluted pathogens.

Decontamination

Decontamination is the combination of physical and chemical processes that kills or removes pathogenic microorganisms and plays an important role in biosecurity. Decontamination rarely achieves sterility; it mostly dilutes the pathogen. Personal decontamination, when properly carried out, permits the safe movement of people on to the farm. Simple cleaning of surfaces by brushing with a detergent solution is effective in removing contaminating pathogens and is fundamental for achieving effective chemical decontamination. Most disinfectants have reduced effectiveness in the presence of fat, grease and organic dirt, so prior cleaning with brushing and detergents is very important. Every effort should be made to remove coverings from all surfaces to be decontaminated so that sun, light and air can boost the process of cleaning with detergent and coating with disinfectant.

Soaps and detergents

Detergents are surface active chemicals used for cleaning. They act as wetting agents, breaking down dirt and emulsifying oils and grease, and holding them in suspension to be washed away. Soaps act in a similar way but are made from fat and potassium hydroxide (KOH) or sodium hydroxide (NaOH; lye) and can be inactivated by hard (calcium- or magnesium-rich) water, whereas detergents are made from chemicals, usually synthetic water-soluble or liquid organic preparations. Soaps and detergents require at least 10 min of contact time for them to be effective as disinfectants.

Disinfectants

Disinfectants are agents, usually chemicals, which destroy, neutralise or inhibit the growth of pathogens on fomites. A fomite is an inanimate object or material that carries infection, such as clothes, utensils or farm equipment. Soaps and detergents are disinfectants in their own right. Preliminary cleaning by mechanical brushing with soap or detergents is highly effective in removing contaminating viruses and bacteria and is almost always necessary before any chemical disinfectants are used. Detergents and hypochlorites (bleach products) tend to be the cheapest disinfectants and hence are the most commonly used. Chlorine is a powerful oxidising agent, effective in killing all viruses and many bacteria and fungi at a concentration of 2–3% available chlorine (usually by diluting one part concentrated household bleach to three parts water) with a contact time of at least 10 min. The effectiveness of hypochlorite is highest in the pH range 6–9 and decreases markedly in the presence of organic material. Hypochlorite powders are readily available as swimming pool disinfectants or household bleaches, and can be diluted for use on site. Hypochlorite solutions are not chemically stable and decompose rapidly as temperatures rise above 15°C. They can be corrosive to metals and should not be used on hands, face or skin. Virkon® is another highly effective disinfectant.

Safety

All disinfectants must be used with care to avoid animal or human health problems. When mixing disinfectants, always add the concentrate to water, and never water to the concentrate. Protective clothing and equipment should be used and care taken not to inhale mist created during application. Disinfectants should be washed off the skin immediately with copious amounts of water.

ANIMAL HEALTH

The health and husbandry of beef herds is maintained far more on a herd level than on an individual animal basis. The latter is possibly a feature of the health and husbandry of bulls, some individuals in feedlots or breeding cows when obstetrical intervention is required, but on the whole it is the evaluation of the whole production system and intervention at the management level that ensures a beef enterprise is productive and profitable.

In a review of the main animal health problems in the Australian beef herd, Sackett *et al.* (2006) identified (in order) cattle tick, undernutrition, bovine ephemeral fever and buffalo fly as having the highest economic impact, broken down into costs associated with either reduced income or increased expenses (Fig. 13.1). In northern systems, cattle tick and undernutrition were the highest cost diseases while in the south, bloat and gastrointestinal parasites were associated with the highest costs. In feedlots, bovine respiratory diseases had the most significant health cost.

This chapter covers these diseases plus others that, although impacting less on the economic viability of production systems, a producer may encounter as either a cause of ill health or death in their cattle. They include animal health issues that affect seedstock producers, cow–calf enterprises and feedlots in both the southern temperate (Chapter 10) and the extensively grazed, pastoral areas of Australia (Chapter 9). This chapter is divided into the diseases and syndromes that affect the four different categories of animals within the beef system, namely calves, weaners and finishers, breeding cows, and bulls, and includes a brief discussion of their economic impacts. Table 13.3 is a summary of the diseases covered in this chapter, their economic importance and distribution.

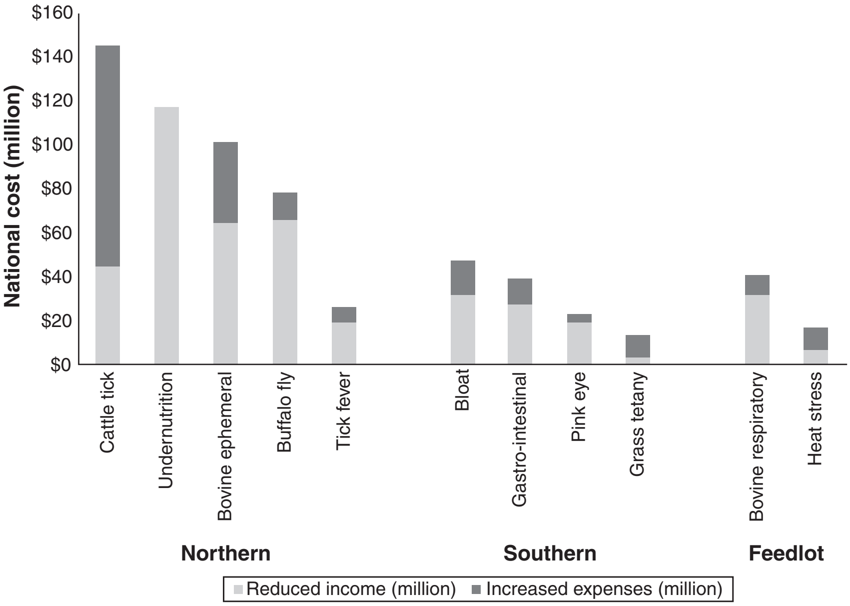


Figure 13.1: Animal health issues that affect beef cattle and their economic significance. Source: Sackett *et al.* (2006).

The key pillars of maintaining good herd health are three-fold. Above all, the provision of adequate nutrition of suitable quantity and quality for animals in different physiological states, ensures a healthy production system. Although simple to articulate, this concept is much more complicated at a practical level (Chapters 11, 16, 18). Beef cattle that are supplied with adequate nutrition are more fertile, finish quickly and supply profit to producers. The source of many individual and herd diseases lies in the provision of unsuitable nutrition.

The second key aspect of maintaining good herd health is careful reproductive management, which is often directly linked to nutritional status. This chapter addresses some of the diseases that affect breeding cows and their calves. The selection, examination and care of bulls is covered in Chapter 14. A beef cow needs to have one calf per year for the herd to function at its most profitable level, a simple target for all beef producers yet often difficult to achieve, particularly in the northern regions of Australia.

Finally, a consciousness of biosecurity and disease prevention is important. This includes the strategic use of vaccines and drenches, early intervention upon identification of a disease outbreak and the implementation of biosecurity practices that are practical and cost-effective.

Calves

The income derived from a beef cow–calf enterprise is from the sale of animals either as young cattle that supply finishing systems, on-sellers or abattoirs directly, as culled cows (Lucy 2004) or as live cows to be used as breeders on other farms. The fundamental premise of a productive beef enterprise is a calving interval of 365 days (Chapters 14, 18). So-called ‘calf survivability’ encompasses the ability of the dam to give birth to a live calf and the ability of that calf to survive the neonatal period, develop into a functioning ruminant animal and survive and grow to a suitable weaning weight when it can be sold. These young animals with their developing immune system are often very vulnerable to disease, and looking after the health of calves is a priority if a production system is to be successful.

Peri- and post-natal death

‘Peri-natal’ death refers to the period immediately before, during and after parturition. Although this period is not specified in terms of number of days, it is usually considered to be between one week before and one week after birth. Calves die for many reasons during this period, such as in utero infections causing abortion, stillbirth and weakness (Mickelsen and Evermann 1994), failure of passive transfer of immunity (Besser and Gay 1994), congenital defects (Rosseaux 1994), respiratory disease (Poulsen and McGuirk 2009), environmental factors and calving management practices (Townsend 1994) and dystocia (Rice 1994). Agents that cause late-term abortion will contribute to pre-parturition loss of calves, but

Table 13.3: Diseases, their economic importance (AUD$) and distribution

Disease	Economic significance or cost	Distribution	References
Peri- and post-natal death of calves	Significant but difficult to quantify	2–3% in southern herdsUp to 25% in northern herds	Sullivan and O'Rourke (1997); Entwistle and Fordyce (2003)
Failure of passive transfer of immunity	Significant owing to its impact on all aspects of calf health	All breeding enterprises across Australia	Beam et al. (2009); Galyean *et al.* (1999); Weaver*et al.* (2000); Wilson *et al.* (1999)
Neonatal calf diarrhoea	Minor significance on a national scale but can have devastating impact at an individual herd level	Southern, cow–calf enterprises	Brooks *et al.* (1996); Bazeley (2003); Constable (2004); MLA(2005b); Smith (2009)
Gastrointestinal parasites	$38 million per year	Mainly southern grazing systems	Craig (1988); Waller (1997); Sackett *et al.* (2006); MLA (2011a, 2012b); Sutherland and Leathwick (2011)
Infectious bovine keratoconjunctivitis	$24 million per year	Finishing enterprises, cow–calf enterprises in southern regions	Sackett *et al.* (2006)
Bovine respiratory disease complex	$40 million per year	Feedlots	Galyean *et al.* (1999); Cusack *et al.* (2003); Sackett *et al.* (2006); Cooper and Brodersen (2010); Edwards 2010); MLA (2010); Larson and Step (2012)
Ruminal acidosis	Minor significance on a national scale but can have devastating impact at an individual herd level	Feedlots	Kleen *et al.* (2003); Nagaraja and Lechtenberg (2007a, b); Nagaraja and Titgemeyer (2007)
Bloat	$46 million per year	Southern grazing enterprises mainly confined to NSW but occurs sporadically where cattle are grazed on annual pastures	Sackett *et al.* (2006); Greenall and Graham (2011)
Bovine viral diarrhoea	No current Australian data	Nationwide in all beef enterprises	Brock (2004a, b); Campbell (2004); Chase *et al.* (2004); Kelling (2004); Smith and Grotelueschen (2004)
Plant poisoning	Minor significance on a national scale but can have devastating impact at an individual herd level	Mainly southern grazing enterprises	
Ticks	$146 million per year	Mainly pastoral cattle	Johnston and Sinclair (1980); Sackett *et al.* (2006)
Anaplasmosis and babesiosis (tick fever)	Minor significance ($20 million per year)	Pastoral cattle in tick-endemic areas of northern Australia	Jonsson *et al.* (2008); MLA (2011b)
Buffalo fly	Major significance (up to $80 million per year)	Mainly pastoral cattle but some intensively grazed herds where buffalo fly is endemic	Williams *et al.* (1985); MLA (2003); Sackett *et al.* (2006)
Bovine ephemeral fever	Major significance (up to $100 million per year)	Kimberley area of WA, the Barkly Tableland in the NT and from the Queensland–NSW border to the eastern districts of Victoria	Uren (1989); Kirkland (2002); Walker (2005)
Bovine Johne's disease	Minor significance but subject to government surveillance and disease-free accreditation schemes	Mainly restricted to Victoria and southern NSW	Parkinson *et al.* (2010); AHA (2012a)
Ocular squamous cell carcinoma	Accounts for 22% of all carcass condemnations	Restricted to *Bos taurus* cattle – mainly Herefords	Spradbrow *et al.* (1977); Parkinson *et al.* (2010); Tsujita and Plummer (2010)

equally stress, occasioned by such things as inclement weather, transport or malnutrition, is responsible for a proportion of pre-term calf loss.

'Post-natal' refers to the period between birth and weaning. Calf death is recognised as a significant source of loss and reduced profitability in extensive grazing systems such as those found in the north-west of Western Australia and northern Queensland (Bellows *et al.* 1987). Peri-natal and post-natal losses are estimated as ranging from 3–5% in southern beef herds (Entwistle and Goddard 1984), while the figure in pastoral cattle is deemed to be as high as 25% (Sullivan and O'Rourke 1997). It is estimated that in pastoral cattle a high proportion of post-natal losses occur by 14 days after birth (Holroyd 1987) and it is often very difficult to determine the cause of death because breeding cows graze and calve on large pastoral holdings and are often not seen for 12 months at a time. Large herd sizes, high costs of mustering and remoteness from laboratory facilities also hamper efforts to identify specific causes of such calf losses. Nevertheless, calf deaths can be broadly classified as attributable to:

- late-term abortion;
- dystocia – more common in heifers than cows;
- mismothering;
- misadventure – drowning, breaking limbs;
- exposure – heatstroke or hypothermia;
- predation – mainly foxes, eagles or dingoes;
- infectious diseases.

On beef farms that utilise improved pastures and are more intensively managed, calf deaths are most often attributable either to dystocia or to infectious disease, the former usually predisposing calves to the latter. On this type of beef enterprise, good management and early intervention can often make a difference to the number of calf deaths. The next sections will discuss specific diseases and syndromes and how they can best be managed.

Failure of passive transfer of immunity

Neonates have underdeveloped immune systems and rely on the transfer of immunoglobulins (Igs), also known as antibodies, from the mother to protect against infectious disease (Besser and Gay 1994). Igs are proteins, and IgG is the main Ig in colostrum, constituting 85% of the total (Parkinson *et al.* 2010). Other Igs that play an important role in the transfer of immunity to the calf, namely IgM and IgA, make up the remaining 15%.

Transfer of immunity occurs via the ingestion and absorption of colostrum by the newborn calf; this process is referred to as passive transfer of maternal immunity. Calves can only absorb Ig from the colostrum in the first 24 h after birth (Weaver *et al.* 2000). The failure of passive transfer (FPT) is a condition whereby, for various reasons, the calf doesn't acquire sufficient Ig from colostrum to protect it from infectious disease. The two most effective means of ensuring good calf survival are adequate passive transfer and the minimisation of dystocia.

Reviews of the many reasons for FPT are available (Besser and Gay 1994; Wikse *et al.* 1994; Weaver *et al.* 2000). For there to be good passive transfer a calf must be able to stand, walk, find the dam's teats and suckle, and the dam must be able to stand, bond with the calf, produce colostrum with adequate concentrations of Ig and have teats that can be grasped by the calf. Anything that interferes with this will contribute to FPT.

Vulnerable calves need to be supplemented with colostrum. The best way to do this is to provide good-quality colostrum, either freshly milked from the dam or from stores of frozen colostrum, and allow the calf to suck at least 2.5 L of colostrum from a calf feeder. If the calf is too weak or does not have a good suck reflex then the colostrum needs to be delivered directly into the stomach via an oesophageal feeder such as a McGrath calf feeder (Fig. 13.2); at least 4 L of colostrum needs to be given via this method.

When a calf suckles from a cow, it stimulates a reflex closing of the oesophageal groove that effectively funnels the colostrum past the rumen and directly into the abomasum, where most Ig absorption occurs. This reflex closing does not happen when colostrum is given via an oesophageal feed; instead the colostrum is deposited

Figure 13.2: McGrath calf feeder. Source: M. Laurence.

straight into the rumen. For enough colostrum to enter the abomasum and adequate Ig absorption to occur, enough colostrum must be given for it to simply overflow from the rumen into the abomasum.

Neonatal calf diarrhoea

Neonatal calf diarrhoea (NCD) syndrome, also known as calf scours, kills beef calves in Australia. Although calves can scour intermittently until they are weaned, most of those that die from acute diarrhoea (scouring) do so within the first 30 days of life. The disease presents as either a few sporadic cases in a herd every year or in outbreaks where the incidence in a herd is dramatically higher than other years. The disease is multi-factorial, with the infectious agent itself being only one factor (Bazeley 2003; MLA 2005b). Contributing equally to the severity of an outbreak are climatic conditions, stocking rate, husbandry in the breeding herd, vaccination status of cows and paddock hygiene. It is often not clear why an outbreak occurs when conditions are apparently much the same as in other years.

There are several infectious agents, some viral and some bacterial, that can alone or in combination cause NCD. The most common pathogens associated with NCD are enterotoxigenic *E. coli K99* (ETEC), rotovirus and cryptosporidium, a protozoan parasite of the intestinal tract. Other secondary pathogens include *Salmonella* strains, enterohaemorrhagic attaching and effacing *E. coli* and coronavirus. Some of these, like *Salmonella* spp. and ETEC, are of particular concern because they are zoonotic.

There are three main preventative principles, arguably in order of importance:

- prevention of FPT and vaccination;
- minimising the exposure of calves to reservoirs of infection;
- preventing the introduction of new NCD pathogens into calving herds.

Prevention of FPT is vital in protecting calves against NCD. It is possible to vaccinate against several of the main NCD pathogens. There is an effective anti-KPP (ETEC) vaccine (Bovilis E®, Coopers Animal Health) that can be given to cows in late gestation that protects calves that get adequate colostrum against *E. coli*-induced diarrhoea. This is useful if there has been a history of *E. coli* scours on the farm in previous years. There is also a combined *Salmonella* vaccine (Bovilis S®, Coopers Animal Health) that can be given to cows twice, four weeks apart, before calving. Again, protection of calves relies on good passive transfer. There is now a vaccine available in Australia to protect calves against rotavirus (Rotavac, Coopers Animal Health). Vaccination is indicated in a year following a severe outbreak of NCD.

Minimising exposure to NCD pathogens and reservoirs of infection requires management (Vermunt 1994; Barrington *et al*. 2002; Larson and Tyler 2005; MLA 2005b), but the following practical and relatively easy husbandry measures can markedly reduce the incidence of NCD:

- Careful selection of calving paddocks – the calving and nursery paddocks should be selected 12 months before calving starts and differ each year. They need to be accessible to make regular monitoring possible and ideally should have been free of cattle for the six months before the start of calving. Paddocks should be as free as possible from muddy/swampy areas, stagnant water pools and slow-flowing watercourses, and should be protected by adequate windbreaks such as lines of trees. Paddocks that have had animals suffering from NCD should not be used the following year. Cows should only be introduced into the calving paddock the week before calving starts.
- Restricted calving period – restricting the joining period to six weeks for heifers and nine weeks for cows means that age range of calves in the calving paddock is limited. Ideally the calving herd gets split into about three cohorts over the calving period about once every three weeks. Calved cows should be moved to new paddocks as nursery groups.
- Avoid manure build-up – stocking rates need to be low enough to minimise manure accumulation. Water troughs should not leak and it is useful to spread lime or gravel around concrete aprons. Multiple watering points and feeders spread faecal load.
- All-in all-out – this means that dead calves should not be replaced with bobby calves and that cohorts of cows with calves are moved in one go from one paddock to a new nursery paddock. At the end of calving all cows and calves should be removed from the calving paddock.

Prevention of the introduction of new NCD pathogens into calving herds is achieved using the basic principles of biosecurity (discussed earlier in this chapter) and the principles of minimising exposure to NCD.

NCD leads to dehydration, metabolic acidosis, electrolyte imbalances, negative energy balance and overgrowth

Table 13.4: Clinical signs used to detect dehydration and metabolic acidosis in calves with NCD

Dehydration (%)	Acidosis level	Eyeball sunkenness	Skin tent time (s)	Mucous membranes	Clinical presentation	Fluid therapy required
0–4	1	None/slight	1–4	Moist	Bright and alert, strong suckle reflex, warm mouth, cannot be caught	None/possible oral fluids
5–8	2	Slight separation between eyeball and orbit	5–10	Tacky	Standing or sitting quietly, weak suckle reflex, walks away when approached	Oral fluids and electrolytes
9–10	3	Up to 0.5 cm between eyeball and orbit	11–15	Tacky	Depressed, unwilling to stand, sternal recumbency, no suckle reflex, cold mouth, readily caught	Intravenous fluids required
11+	4	Gap between eyeball and orbit is 0.5–1 cm	>15	Dry	Collapsed, moribund, lateral recumbency, no suckle reflex, very cold mouth	Intravenous fluids required

Source: Adapted from MLA (2005b).

of bacteria in the intestine (Parkinson *et al*. 2010). Treatment should be aimed at correcting these impacts in order but the type of intervention depends on the severity of the illness, the percentage of calves affected and the practicality of treating calves.

Dehydration and acidosis are the most serious clinical signs of NCD. Eye sunkenness is the most practical way to assess dehydration in calves. Metabolic acidosis causes depression, ataxia, recumbency, a decreased suckle reflex, coma and death. It is caused by the loss of large amounts of bicarbonate in the diarrhoea. Replacing lost fluids and lost bicarbonate is done using intravenous or oral fluid replacement. Giving fluids by mouth using a calf feeder is the easiest and most practical method and will suffice in most cases, but there comes a point where intravenous fluids are required to save the calf. Table 13.4 provides a brief summary of the clinical signs and types of fluid replacement.

Oral fluids need to replace the lost fluid and contain electrolytes and bicarbonate to correct acidosis and loss of extracellular fluids. Different oral fluid therapy products available in Australia have been reviewed (Cannon 2004; MLA 2005b; Vogels 2010) and many appear effective in restoring electrolyte imbalances, correcting mild to moderate acidosis and providing an energy supply (Table 13.5).

Intravenous (IV) fluids are used when calves are over 8% dehydrated. For best results, calves should be removed from the calving paddock and housed in a shed on a bed of straw, surrounded by hay bales. IV fluids can be given via the jugular or auricular (lateral ear) veins. Antibiotics are not always appropriate when treating NCD. Their use is restricted to when specific pathogens have been identified or if sepsis is suspected. It is advisable to consult a veterinary surgeon regarding the most appropriate antibiotics and when to use them.

Weaners and finishers

Parasitism

Weaners are very susceptible to gastrointestinal parasites. Of the endemic diseases that affect livestock in Australia, external and internal parasitic diseases have the largest financial impact on farm productivity (MLA 2012b). Five of the nine economically most important cattle diseases are either caused or transmitted by parasites (Sackett *et al*. 2006). The management and control of internal and external parasites depends on the type of parasite, the type of production system, the breed of cattle within that system, the geographical location of the enterprise, the class, age of cattle being treated, the prevalence of various parasite-borne diseases in the area and the type of antiparasitic chemicals that are available. A decision on how and when to control different parasites is often made with reference to all these factors and needs to be customised to the requirements of individual producers. However, a good guide to the control and management of parasites is the MLA publication, *Cattle Parasite Atlas* (MLA 2005a, 2012b).

High numbers of internal parasites contribute significantly to weaner disease. The main internal parasites of cattle are the nematodes *Ostertagia ostertagi* (small brown stomach worm), *Haemonchus placei* (barbers pole worm), *Trichostrongylus* spp., *Cooperia* spp. and flukes, *Faciola hepatica*, *Paramphistomum* spp. and *Calicophoron*

Table 13.5: Composition of oral rehydration solutions available in Australia[1]

Product, company and mixing rate			Sodium	Potassium	Chloride	SID[2]	Alkalinising agent		Glucose: Na[3]	Osmolarity[4]	Energy[5]
Recommended values (Smit 2009)			90–130 mmol/L	10–30 mmol/L	40–80 mmol/L	60–80 mEq/L	50–80 mmol/L Acetate, propionate		1:1 to 3:1	500–600 mOsm/L	MJ/L
Bovelyte	ProviCo	90 g/2 L	112	18	46	84	84	Bicarbonate (66) Citrate (18)	1.7	435	0.53
Diarrest sachets	Virbac	248.5 g/2 L	148	31	103	76	60	Bicarbonate (18) Citrate (12) Acetate (30)	1.2	526	1.26
Hydrate liquid concentrate	Bomac	160 ml/2 L	76	15	74	17	2	Propionate	2.3	359	0.38
Hydrate sachets	Bomac	68.5 g/2 L	76	15	74	17	2	Propionate	2.2	347	0.35
Lact-Lyte sachets	Virbac	90 g/2 L	79	28	55	52	47	Acetate (30) Propionate (17)	1.3	328	0.64
Lectade sachets	Jurox	64 g/2 L	73	16	73	16	4	Citrate	2.2	344	0.35
Lite-Scour-Diet	Agvantage	20 g/2 L	12	3	10	5	5	Bicarbonate	4.3	79	0.14
Maxi-Trans	Virbac	20 g/2 L	12	3	10	5	5	Bicarbonate	4.3	79	0.14
Mega-Lyte	Sykes	100 g/2 L	88	0	59	29	29	Bicarbonate	2.5	399	0.62
Mega-Lyte Plus	Sykes	60 g/1.5 L	82	14	46	50	50	Bicarbonate(36) Citrate (14)	1.1	291	0.26
Res-Q	DeLaval	100 g/2 L	173	0	114	59	59	Bicarbonate	2.6	791	1.25
Resus	Dasco	100 g/2 L	84	0	57	27	27	Bicarbonate	2.5	383	0.60
Scourlyte	Novartis	110 g/2 L	89	19	76	32	32	Citrate	1.8	356	0.47
Veanavite Electroguard	Veanavite	60 g/1.5 L	79	14	46	47	47	Bicarbonate (34) Citrate (13)	1.1	285	0.26
Vy'Trate liquid concentrate	Jurox	160 ml/2 L	73	31	73	31	5	Citrate	2.3	373	0.35
Vy'Trate sachets	Jurox	64 g/2 L	73	16	73	16	4	Citrate	2.2	344	0.35

[1] Composition calculated from product labels. Only products whose mixing rates are known are included (MIMS 2011; APVMA 2012).

[2] SID = [Na] + [K] – [Cl].

[3] Glycine (in Hydrate, Lectade and Vy-Trate) is included in the Glucose:Na ratio. It is assumed that the lactose in Diarrest, Lactolyte and Scour-Ade was totally digested.

[4] Osmolarity >700 mOsm/L increases the risk of osmotic diarrhoea and ileus (Smith 2009).

[5] Glucose, lactose and rice flour → ~16 kJ/g, acetate →0.9 kJ/mmol, citrate → 2.1 kJ/mmol, propionate → 1.5 kJ/mmol (Brooks *et al.* 1996). A 45 kg calf on a milk-only diet has a maintenance requirement of 7.26 MJ/day. Excluding Lite-Scour-Diet and Maxi-Trans, these products fed at 4 L/day contain →15–70% of this requirement.

Source: Vogels (2010).

calicophorum. Other nematodes include *Nematodirus* spp. and *Oesophogostomum* spp. Infection with worms begins when animals start grazing pasture but the level of infection depends on the time of calving and whether calves are grazing green or dry pasture. Internal parasites can:

- destroy the cells lining the stomach so it becomes less efficient at digesting nutrients (*O. ostertagi*)
- feed on cells lining the small intestine and cause malabsorption and sometimes secondary bacterial infection (*Trichostrongylus* spp.);
- trigger an immune response or occasionally a serious hypersensitivity reaction from the weaner which damages the gut (nematodes);
- cause tissue damage as the larvae migrate through the body (*F. hepatica*);
- suck blood, causing anaemia (*H. placei*, *Fasciola hepatica*);
- consume the nutrients in the gut and reduce the nutrients available to the animal (tapeworms);
- physically obstruct the gut (tapeworms) (Parkinson *et al.* 2010).

The most significant of these parasites for weaners is *O. ostertagi*. This nematode hatches from eggs in cattle faeces and develops through first, second and finally the third larval stage which then leaves the cattle pat to reside in pasture and soil. The success and speed of development to infective third-stage larvae are enhanced by rainfall and warm temperatures, though *O. ostertagi* development is tolerant of cold and dry periods. Typically, it is only after weaning that calves become vulnerable to parasites so it is often the autumn after weaning when symptoms of parasitism first become evident. Following ingestion of the larvae from the pasture, they mature inside the gut to become adults and complete the life cycle. Infection from *O. ostertagi* presents as Type 1 or 2 Ostertegiasis.

Type 1 Ostertegiasis is caused when weaners ingest large numbers of larvae over a short period and the ingested larvae develop into adults within the gastric glands (Anderson and Waller 1983). This causes damage to the gastric glands, a reduction in the ability to digest food and a loss of protein through the damaged gut wall. The result is a failure to thrive, associated with significant scouring. Weaners often have faecal staining around the tail and on the hocks and can look dull and have a reduced appetite. It is common for most of the animals in a mob of weaners to be affected. A faecal egg count of >1000 eggs/g of faeces is usually enough to confirm the diagnosis of parasitic enteritis, though egg counts in older cattle can be an unreliable indicator of infection (Parkinson *et al.* 2010).

Type II Ostertegiasis is caused by synchronised maturation of arrested larvae to the adult stage within the gastric glands (Anderson and Waller 1983). *O. ostertagi* larvae are able to delay (or arrest) development in the stomach, which is termed 'hypobiosis'. It is probably a result of either an increased host immune response in slightly older cattle or the worms' own response to changing climatic conditions, but the actual reason is not yet known (Ballweber 2006). The larvae can remain dormant for long periods without obvious effects on the host, but suddenly resume maturation when cattle become stressed, for instance at the time of their first calving. This sudden maturation and eruption of larvae from the gastric glands causes sudden and severe weight loss, diarrhoea, protein loss leading to oedema and sometimes death. Usually, fewer animals are affected by Type II Ostertegiasis than by Type I Ostertegiasis. Plasma pepsinogen concentrations rather than a faecal egg count are the best way to diagnose Type II Ostertegiasis because the disease is a result of emerging dormant worms so adult worm burdens may be low. The damage to the gastric mucosa releases large amount of pepsinogen, an enzyme, into plasma. High concentrations reflect gut cell damage.

H. placei is a gut parasite that sucks blood and can cause anaemia and, in cases of severe infection, death. It usually causes disease in late summer and early autumn but the worm doesn't survive well in very cold climates so disease is restricted to warmer regions with summer pasture growth patterns.

Treatment and control of internal parasites depends on:

- using grazing management (rotation and, if possible, alternation with sheep) to minimise exposure to infective larvae on pasture;
- monitoring of worm and fluke burdens in mobs of cattle;
- treating infected cattle with effective anthelmintics;
- minimising the build-up of resistance to drenches.

Pastures can be managed to minimise the number of infective larvae and therefore the rate of infection of animals. Pasture that has been used for cropping is often considered relatively safe because few parasites can survive in faeces through a cropping season. Once these pastures are again available for grazing they are good for weaners, particularly immediately after they have been treated with anthelmintics, but this can place pressure on development of drench resistance. Similarly, crop stubbles have low contamination levels, but often do not provide adequate nutrition for weaners. Some producers graze pastures with mobs of adult sheep or cattle before putting weaners onto the pasture. Adult animals have more resistance to worms and sheep generally do not share the same internal parasite species, and therefore are useful to lower the number of infective larvae on pastures.

The easiest way to monitor worm burdens in young cattle is with faecal egg counts (FEC). FEC is not suitable for older cattle (more than 15–18 months of age) as it is not a good predictor of worm burden. A 5 g sample needs to be collected per rectum (or from distinct, fresh cattle pats) from at least 10 animals in a mob and submitted to a laboratory where the total number of eggs/g is measured. FEC will also allow assessment of pasture management strategies on infection of cattle. Avoiding unnecessary drenching helps to slow drench resistance.

There are three main classes of broad-spectrum cattle anthelmintic: benzimidazoles (e.g. oxfenbendazole, fenbendazole – the white drenches), imidazothiazoles and pyrimidines (e.g. levamisole and morantel – the clear drenches), avermectins and milbemycins (e.g. moxidectin, abamectin – the macrocyclic lactones). Traditionally these have been used alone, or more recently in combination, to treat internal parasites in cattle. Producers have been encouraged to use a different class of drug at each drenching to minimise the development of resistance. These products can variously be given by mouth, as injections or as pour-on products where the active ingredient is absorbed through the skin. A new class of drench, the amino-acetonitrile derivatives, has been registered recently as a commercial product for use in sheep. Currently there is no product from this class available for use in cattle.

Waller (1997) among many others predicted an increase in anthelmintic resistance in cattle and this proved to be correct (Sutherland and Leathwick 2011; Kaplan and Vidyashankar 2012). It is certainly no longer the case that producers can be confident that the drench they give to weaners will be effective. Underdosing and inappropriate use of pour-on products such that their absorption is suboptimum have been postulated as reasons why resistance is increasing in worm populations. Several strategies can be used to minimise the increase of drench resistance but the use of refugia has lately been identified as having a significant impact on reducing drench resistance in sheep (Van Wyk 2006) in some environments.

The worms in refugia are those not exposed to anthelmintics. These worms can potentially maintain a genetic pool for sensitivity to drenches and therefore help to dilute the number of resistant worms in a population. The idea is that the number of worms susceptible to drenches greatly outnumbers the number of resistant worms. Maintaining high numbers of worms in refugia is usually made possible by:

- deliberately not drenching all animals in a mob of cattle and choosing animals that are underweight or scouring for drenching;
- keeping animals on infected pastures for a week after drenching before moving them to clean paddocks;
- treating only mobs of cattle where FECs indicate that treatment is warranted. This usually means avoiding treating adult cattle.

Parasite burdens, types of parasites and the best treatment and control options depend on region. The MLA has developed an easy-to-use interactive website that summarises these aspects for each cattle-producing region in Australia (MLA 2011a).

Infectious bovine kerato-conjunctivitis

Infectious bovine kerato-conjunctivitis (IBK), also known as pinkeye, is a disease that can have a major impact on production and profitability, particularly in young, finisher cattle. In 2006 IBK cost Australian producers an estimated $22 million in lost production with a further cost of $1.5 million for treatment (Slatter *et al.* 1982; Sackett *et al.* 2006). It is a common, highly contagious ocular disease of cattle of all ages but it usually affects young animals. It affects one or both eyes and can be painful. It causes significant economic losses because there is often significant reduction in growth rate or even weight loss in affected animals, and because some animals lose sight in their eyes altogether when damage and scarring of the cornea is severe. There is a higher prevalence in *Bos taurus* breeds, particularly white-faced breeds, than in *Bos indicus* cattle. The incidence varies but can be as high as 45% in some herds in summer.

The infectious agent is *Moraxella bovis*, a gram negative bacillus, but others, such as *Mycobacterium bovis* and *Moraxella lacunata*, can also contribute to the symptoms of IBK. The major predisposing factor is damage to the cornea. This can be caused by ultraviolet light, dust or feed particles or physical trauma from seeds or sticks. Hence the disease is most common in summer. *M. bovis* uses microscopic pilli to adhere to the cornea and the haemolytic endotoxin called cytolysin that the pilli produce is highly corneotoxic. The infection inevitably leads to inflammation of the eye and periorbital tissues and usually to a corneal ulcer (Fig. 13.3).

Figure 13.3: Steer with IBK. Note corneal oedema and marked purulent discharge. Source: M. Laurence.

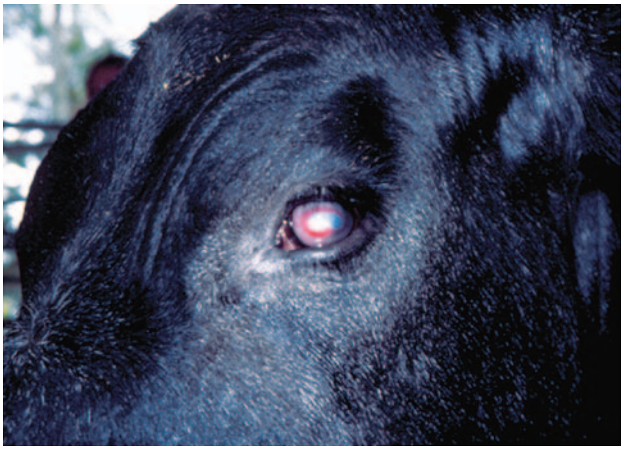


Figure 13.4: Eye in the healing phase after severe infection with IBK. Note corneal scarring and oedema. Source: M. Laurence.

Clinical signs are usually rapid in onset and often come in the form of an outbreak affecting a large percentage of the mob. There is usually ocular discharge, corneal oedema, central ulceration and opacity, hypopyon and weight loss associated with infections.

Control relies on the management of dust and prevention of overcrowding. Transporting healthy animals with diseased animals is a surefire way to spread IBK through the entire mob. Medical treatment involves the use of parenteral antibiotics like Tilmicosin given subcutaneously at 10 mg/kg (Zielinski *et al.* 2002), oxytetracycline, topical application of cloxacillin eye ointment (Orbenin, Beecham Vet.) for at least three days and sometimes intrapalpebral subconjunctival injection of procaine or benzathine. Penicillin and dexamethasone are required to manage pain and inflammation. These drugs are absorbed over 70 h and the procedure has often been effectively used as a one-dose treatment to treat cases of pinkeye in feedlot cattle (Fig. 13.4). Commercial eye patches are available to cover infected eyes.

A vaccine is available in Australia – Piligard® (Coopers Animal Health). This trivalent vaccine is the only vaccine available for cattle. It is a one-dose, inactivated *M. bovis* vaccine in an oily adjuvant. A 2 mL dose is injected either subcutaneously or intramuscularly in the anterior third of the neck, or in the ischiorectal fossa (Colazo *et al.* 2002). It can be used in all classes of beef and dairy cattle as young as one week of age. It should be administered three to six weeks before the expected onset of the pinkeye season. It is usually used to protect the youngest, most vulnerable cattle in the herd, namely weaners and first calving cows, but is also very useful to prevent outbreaks of IBK in young cattle in feedlots. The oil adjuvant can cause a transient local reaction at the vaccination site that can persist for several weeks. Hypersensitivity reactions have been recorded which have caused temporary reduced milk output in lactating cattle. Adrenalin should be used in the rare case of an allergic shock reaction. Great care should be taken to avoid self-injection, which may cause an inflammatory reaction or an allergic response. Autogenous vaccines have been tested but their efficacy has not been clearly demonstrated (O'Connor *et al.* 2011).

A key aspect of the management of IBK is to identify at-risk cohorts of animals and act accordingly. Young animals, animals that have been transported (particularly in summer) and animals housed in dusty environments are all vulnerable to infection. Pre-transport vaccination, control of dust and methods of feeding and careful observation of these groups of animals helps to minimise the incidence and therefore the impact of IBK.

Feedlot diseases

A feedlot can be broadly defined as a confined yard area with watering and feeding facilities where cattle are completely hand or mechanically fed for the purposes of production. By definition, feedlots (Chapter 11) are environments where cattle are exposed to high pathogen loads and conditions that predispose them to disease. Both animal and environmental factors (Chapter 11) contribute to the development of several serious diseases, including:

- transport to the feedlot;
- mixing cattle of different ages, breeds, sources, immune status and social groups;

- close contact between animals;
- high concentrate-based rations;
- varying amounts of shade, often dusty and limited protection from extremes of weather;
- areas in pens that are very boggy.

These factors induce stress in young animals entering the feedlot and this is always accompanied by a transient depression of the immune system, which is usually not particularly well developed because of the age of the animals. The rest of this section addresses the main feedlot diseases and how best to manage them.

Bovine respiratory disease complex

Bovine respiratory disease complex (BRD) refers to the group of respiratory diseases that can affect feedlot cattle. The main clinical signs include pyrexia, nasal discharge, inappetence, lethargy, coughing, dyspnoea and an extended head and neck, droopy ears, ocular discharge, evidence of pneumonia on clinical examination, recumbence and, in some cases, death. The severity of BRD in an individual depends on its age, immune status, vaccination history, type of causative agent of the infection and the degree of intervention and treatment. Management of BRD starts at the point of purchase of the cattle because some cohorts of cattle are more predisposed to the syndrome than others. A group of *Bos taurus* cattle with no vaccination history, that has been weaned on to a truck, transported for a long period to a saleyard where it has been mixed with other cattle and then transported to the feedlot, is more likely to suffer from BRD than backgrounded cattle that have been trucked a short distance from the farm of origin to the feedlot.

BRD is the most economically significant disease of feedlots. It accounts for ~50% of feedlot deaths and up to 90% of feedlot illness (Sackett *et al*. 2006; Edwards 2010; MLA 2010). There are huge costs associated with the poor growth rates of affected animals, reduced feed conversion efficiency, cattle deaths, management, monitoring and medication and vaccination. MLA estimated the cost of BRD in unvaccinated animals at $20/head (Sackett *et al*. 2006) and in total the disease costs the feedlot industry $40 million a year (Oswin 2012).

Causes of BRD are multi-factorial. Most disease occurs in feedlot cattle in the first 21 days after induction, with most cases occurring at about day 10. The signalment (age, sex etc.) of the cattle, weaning history, vaccination status, breed, transport distance and time are all factors that make an animal more or less vulnerable to disease. There is a host of infectious agents that cause BRD, both alone and in combination. Table 13.6 describes the viral initiators and the secondary bacterial opportunistic invaders.

The viral initiators are the viruses that are usually the first pathogens to infect the animals that suffer from BRD (Ridpath 2010). They are on the whole fairly ubiquitous in feedlots and are often associated with a transient pyrexia, inappetence and flu-like symptoms such as nasal and ocular discharge. The viruses replicate in the upper respiratory tract of the infected animals, which quickly become a source of infection for other animals in the feedlot. Importantly, these viruses, particularly BVD, cause a marked period of immunosuppression which allows environmental, opportunistic, secondary bacteria to invade the respiratory tract and cause the severe symptoms associated with lower respiratory tract infection and pneumonia. When viral respiratory disease progresses to bacterial pneumonia, BRD becomes difficult and expensive to treat.

The best chance of achieving a successful treatment of a BRD case is to identify it early, isolate the animal and treat aggressively (Nickell and White 2010). Cattle with the advanced lung lesions caused by chronic pneumonia are very difficult to treat successfully. They invariably cost more to treat than they realise in profits if they are ultimately sold. This point alone highlights the need for early identification and treatment of BRD.

In an ideal situation, pens of animals are checked by pen-riders every day. This is best done quietly, on foot or

Table 13.6: Infectious agents associated with BRD

Primary viral initiators	Secondary bacterial agents
Bovine herpesvirus type 1.2 – infectious bovine rhinotracheitis virus (IBR)	*Mannheimia haemolytica*
Bovine viral diarrhoea virus (BVDV)	*Pasteurella multocida*
Bovine respiratory syncytial virus (BRSV)	*Histophilus somni*
Parainfluenza Type 3 virus (PI3)	*Actinomyces pyogenes*
Mycoplasma bovis (not a virus)	
Bovine coronavirus	

Figure 13.5: Calf with BRD. The outstretched neck, open mouth breathing and poor condition indicate secondary infection. Source: M. Laurence.

on horseback, to minimise the disturbance of resting or eating cattle. Pen-riders should be trained to look for the early signs of BRD, namely, an animal with a mild ocular or nasal discharge with an intermittent cough that tends to hang back from the feedbunk or doesn't want to eat at all. These animals should be removed and checked for pyrexia (Fig 13.5). A body temperature over 40°C indicates infection with a virus. Isolation and treatment should follow until symptoms disappear.

Medical treatment should be a combination of antibiotics and non-steroidal anti-inflammatory drugs (NSAIDS) (Table 13.7). Antibiotics need to be broad-spectrum, long-acting and effective against the common BRD pathogens (Francoz *et al.* 2012). NSAIDS are effective because they reduce fever so the animals start eating sooner. They also have an anti-endotoxic effect that minimises the physiological impact of the bacterial infection.

Prevention of BRD ultimately depends on minimising the stress on cattle pre-entry to the feedlot. However, the strategic administration of vaccines can significantly reduce the incidence of BRD (Table 13.8). Vaccines are of most use when they are given at least a month before transportation to a feedlot but some suggest certain vaccines be given at the time of induction to reduce the incidence and severity of disease (Larson and Step 2012).

Ruminal acidosis

Most of the other significant diseases that affect feedlot cattle are related to nutrition. Of these, ruminal acidosis is the most common and the most serious (Chapter 16). In feedlot cattle there is a rapid transition from pasture and milk to a concentrate-based total mixed ration. One of risks is that this transition results in a change in the microenvironment of the rumen and a metabolic acidosis develops. This can be mild or severe, and death is not an uncommon consequence. This condition has been variously referred to as grain poisoning, grain overload, lactic acidosis and rumenitis.

Acidosis results when cattle eat fermentable carbohydrates (CHO) in amounts sufficient to cause an accumulation of organic acids in the rumen, with a concurrent reduction in pH (Nagaraja and Titgemeyer 2007). These acids are the product of CHO fermentation by rumen microbes and are normally absorbed and metabolised as an energy supply. Acidosis results when the production of acid outweighs the rate of absorption and overcomes the buffering by bicarbonate-rich saliva of the pH in the rumen.

Acute ruminal acidosis results from the rapid ingestion of large amounts of fermentable CHO, or from the ingestion of a CHO-rich diet when there has been no adaptation by the rumen microbes to the diet. Feedlot cattle are most at risk of acute ruminal acidosis during the induction phase and until the diet reaches its maximum grain percentage. The grains associated with the highest risk of acidosis are (in order) wheat, triticale, barley, oats, sorghum and maize (Parkinson *et al.* 2010).The clinical signs of acute acidosis become apparent 12–36 h after grain engorgement and cattle can die as quickly as 8h after engorgement.

Table 13.7: Antibiotics and NSAIDS commonly used in the treatment of BRD

Antibiotics	Duration of action	NSAID	Duration of action
Oxytetracycline	~5–7 days	Tolfenamic acid	48 h
Ceftiofur (daily)	24 h	Meloxicam	72 h
Tulathromycin	~8–10 days	Flunixil	24 h
Florfenicol (rpt once)	48 h		
Tilmicosin	~3 days		

Source: Adapted from MIMS (2011).

Table 13.8: Vaccines available in Australia for the prevention of BRD

Vaccine	Protects against	Dose
Bovilis MH (Coopers Animal Health)	*Mannheimia haemolytica*	2 doses 4 weeks apart – subcutaneous injection
Bovilis MH + IBR (Coopers Animal Health)	*Mannheimia haemolytica* + IBR	2 doses 4 weeks apart – subcutaneous injection
Rhinogard (Zoetis)	IBR	1 dose – intranasally
Pestigard (Zoetis)	BVDV	2 doses 4 weeks apart – subcutaneous injection

Source: Adapted from MIMS (2011).

Subacute ruminal acidosis (SARA) is the less severe form of the disease and is caused by a less marked overproduction of acid and pH decline. Rumen pH will generally fall in the range of 5–6 but it is mainly the proportion of the various organic acids within the rumen that reflects the degree of SARA (Kleen *et al*. 2003). SARA is caused by either a poorly formulated ration, insufficient fibre length in the ration, inappropriate adaptation times or a too rapid transition from one grain percentage to the next as the feedlotter aims to maximise growth through the provision of a very high concentrate diet.

Treatment of acute acidosis must be done at the earliest possible opportunity. The key to success is the substitution of hay for concentrated feed. Correction of dehydration and buffering of the rumen are the next steps, with the delivery of up to 15 L of oral fluids with magnesium hydroxide added at a rate of 1 g/kg liveweight given as a bolus via a stomach tube. Antibiotics, and injection of NSAIDs to counter the endotoxaemia, are also indicated. As a rule of thumb, if an animal is recumbent, more than 8% dehydrated and has total rumen stasis, the chances of a successful treatment are virtually nil. Heroic surgical treatments are possible but the practicalities of a feedlot dictate that euthanasia is the kindest option for these animals.

Good nutritional management prevents SARA. Prevention is easier than treatment because the clinical signs are less obvious than those of acute acidosis. Factors such as the type and amount of grain fed, the mode of delivery, bunk management, type of feed processing (hammer or roller mill), length of the fibre particles in the ration (minimum 10 cm for adequate rumen functioning) and type of feed additives used should all be considered. Feedlotters often consult professional nutritionists for advice on how best to minimise the risk of SARA.

Ionophores, particularly monensin, are widely used to mitigate the risk of SARA (Burrin and Britton 1986). The mode of action of monensin is not well understood but it serves to modulate feed intake and possibly has some antimicrobial effects that modify the acid-producing microbes in the rumen. Nowadays feedlotters need a veterinary prescription to add these to rations.

The addition of grain by-products, such as brewers' grain, is becoming more common because these can partially substitute for the grains themselves and still provide the energy required for growth. Most of the starch has been removed from these products, so the extent to which the ration will induce acidosis is markedly reduced. It has been suggested that the addition of these by-products to feedlot rations has been the single most significant factor in the reduction of the incidence of SARA in feedlots (Nagaraja and Lechtenberg 2007a).

In feedlot cattle, laminitis regularly follows an episode of acute acidosis (Stokka *et al*. 2001) and is one of the first presenting signs of SARA (Kleen *et al*. 2003). Treatment is through the modification of the ration and resolution of the acidosis as well as the administration of NSAIDs to reduce endotoxic injury and mitigate pain.

Sudden death syndrome

The term 'sudden death' is used when death occurs within 24 h of observed clinical signs. In beef herds the time span between first symptoms and death of cattle is not always known because of the irregular inspection of stock and the term 'found dead' may be more appropriate because true sudden death by definition has a very short illness associated with it. Area knowledge is very important since the causes of cattle deaths vary greatly between different regions. This section will address the most common causes of sudden death in beef cattle. It is not a comprehensive list of diseases that kill cattle quickly; the focus is on those diseases that have a significant impact on productivity and profitability.

Clostridial disease

Clostridia are bacteria that are obligate anaerobes. They are in the genus *Clostridium* and are gram-positive rods that have the ability to form spores. Most damage done through clostridial infection is due to the action of toxins released from the bacteria. Thus, disease caused by

Clostridium spp. should more correctly be called intoxication (Rings 2004). Clostridial bacteria commonly thrive on soils rich in humus, particularly heavy clay soils. Clostridial bacteria form exotoxins that are extremely potent. These toxins are formed either in the intestines of animals (*C. perfringens*) or in the liver (*C. haemolyticum*), or they are ingested – preformed on rotting vegetation or the bones of dead animals (*C. botulinum*) or from contaminated silage or water.

The most significant diseases for beef cattle are tetanus (*C. tetani*) and botulism (*C. botulinum*). Both produce neurotoxins and confine their action to nervous tissue and both will cause death in cattle. Death from clostridial infections, except in the case of botulism, do not usually occur in outbreak but are usually sporadic.

Bloat

Bloat costs producers $47 million per year but its impacts are restricted to the parts of Australia with the types of pastures that cause bloat, namely the New England region of New South Wales (Sackett *et al.* 2006). These authors modelled the cost of bloat to be about $17/head in high-risk herds where no prevention is used. Sporadic outbreaks of bloat also occur in other southern parts of Australia where cattle are fed on annual pastures.

Bloat is also known as ruminal tympany, pasture bloat or frothy bloat (Chapter 16). It occurs in pasture-fed animals and is caused by the production of abnormally stable froth in the rumen that traps the normal gases of rumen fermentation. The stable froth prevents normal eructation. A common scenario is that animals have been grazing dry pasture or pasture with suboptimal amounts of energy and protein, are moved to new, lush pastures and are found to be bloating or dead as soon as a few hours later.

Normally bloat occurs from rapid ingestion of lush, immature, rapidly growing legumes such as clover, or pasture. Some cows have a genetic predisposition to bloating. First-time exposure to new pasture is a common cause of the problem. The following symptoms are commonly seen when cattle die of primary bloat: carcasses are obviously bloated and begin decomposing rapidly, eyes are prominent, conjunctiva are congested or haemorrhagic, and there is often a bloat line in the oesophagus.

Treatment is to immediately remove affected animals from offending pasture and feed them hay to stimulate rumen movement. Physical decompression with oral tubes or rumen trochars is sometimes indicated. Various anti-bloating agents are marketed to minimise the risk of bloat; some, such as anti-bloat liquids or paraffin oil added to water, are given to individual animals, and others are detergents sprayed on pastures regularly during the bloat season. Intra-ruminal capsules of monensin have been shown to be effective in controlling bloat. Greenall and Graham (2011) provide a good summary of available prevention options.

Bovine Viral Diarrhoea Virus (pestivirus)

Bovine viral diarrhoea virus (BVDV) is an economically important pathogen that affects cattle of all ages and in all cattle-producing systems – breeding herds, feedlots and dairies. It has a worldwide distribution, including Australia. It has been estimated that as many as 90% of the beef herds in Australia are exposed at some point. BVDV causes a variety of clinical manifestations in cattle and can affect the reproductive, immune, respiratory and alimentary systems, as well as causing congenital infections, i.e. infections transmitted from the mother to an embryo or foetus, and abortion. It is one of the most important production-limiting diseases. Economically, the most significant consequences associated with BVDV are its relationship with BRD in feedlots and poor reproduction rates in cow–calf enterprises. The following is a detailed description of the pathophysiology, clinical consequence and control of BVDV. It is included in this section on weaners and finishers but is equally applicable to breeding cows and to bulls.

BVDV is classified as a pestivirus within the Flaviviridae family. These are enveloped RNA viruses (Brock 2004b) that are antigenically similar to the viruses responsible for swine fever and ovine border disease. There are two sources of infection for animals:

- adult animals with transient infections that become viraemic and shed virus for a short time before their immune system overcomes the infection and they become virus-negative (but antibody-positive) again;
- persistently infected (PI) animals that are born immunotolerant to the virus, never clear the infection, and shed massive amounts of virus their whole lives.

An animal can become PI in one of only two ways:

- if its dam is exposed to the virus for the first time during pregnancy, between days 18 and 125. Adult cattle with immunity to the virus from previous exposure cannot produce PI calves. The foetus develops immunotolerance to the virus and therefore

  fails to develop an antibody response or eliminate the virus. These calves may appear clinically normal when they are born but they shed huge quantities of virus in secretions and excretions. It is generally estimated that around 1% of the population is persistently infected. The virus is unlikely to persist in the environment for more than 14 days; it is also susceptible to a range of disinfectants including chlorhexidine;
- occasionally a PI heifer will survive to become sexually mature, fall pregnant and have a calf. That calf will always be PI. This accounts for only ~10% of PIs given the fact that most PI animals die before they reach reproductive age.

Naïve adult animals that are exposed to BVDV often develop a transient, flu-like, upper respiratory disease, characterised by pyrexia, clear nasal discharge, immunosuppression and occasionally a bout of watery diarrhoea. This diarrhoea syndrome is known as bovine viral diarrhoea but is uncommon in Australia.

Infected cattle stay viraemic for ~10 days in which time they are infective to other animals. Antibodies are detectable about three weeks after infection. The marked leukopaenia (neutropaenia) with or without thrombocytopaenia that occurs with BVDV infection often leads to concurrent or secondary infections such as mastitis, metritis, *Neospora* and infection with all the agents of BRD (Campbell 2004).

Outbreaks occur when PI animals or transiently infected animals are introduced to a BVDV-naïve herd. During outbreaks, the virus can be spread by direct contact with acutely infected animals. Mechanical transmission by biting insects or on blood-contaminated needles, nose tongs etc. can also occur. It is important to remember that passage of the virus between animals is not dependent on arthropod transmission (unlike Togaviruses). The incubation period is five to seven days. Most outbreaks occur in herds that are either not vaccinated or are improperly vaccinated.

Infection results in a wide spectrum of clinical manifestations ranging from subclinical to fatal disease. The outcome following infection depends on viral factors (type I *v.* type II, and CP *v.* NCP), host factors (immune status, pregnancy status, gestational age of the foetus at the time of infection), and the level of environmental stress.

By far the most severe impact of the disease occurs when a foetus is infected in utero (Grooms 2004). The outcome depends on the stage of pregnancy when infection occurred. Outcomes can simplistically be classified into three categories:

- early embryonic death – infection between 0 and 45 days;
- production of immunotolerant PI calves that may or may not develop mucosal disease (MD) – infection between 18 and 125 days;
- late-term abortion, peri-natal death or born with defects – infection between 100 and 150 days

PI cattle have a high mortality rate; <10% survive to two years of age. Some appear weak and ill-thrifty at birth, but others are clinically normal. They have a high rate of other diseases.

MD occurs only in PI cattle, mostly before two years of age. Clinical signs include fever, anorexia, profuse watery diarrhoea, blunting of the oral papillae, and oral, nasal, interdigital and gastrointestinal ulcerations. Severe leukopaenia occurs. Prognosis is hopeless for calves with MD and more than 90% die soon after clinical signs appear. Some calves develop a chronic form of MD with recurrent bouts of diarrhoea, weight loss, debilitation, anorexia and chronic oral erosions. They invariably die after several months of illness.

Control of BVDV infection is through vaccination and good biosecurity practices. Vaccine choices in many countries include both modified live and killed products (Kelling 2004), but in Australia there is currently a single inactivated product available (Pestigard, Zoetis). In affected herds the identification and elimination of PI animals and their offspring is vital for control of the disease. However, many producers choose to accept the 'endemic' status of BVDV in their herd and through careful management of the breeding herd can usually escape the most serious consequences of BVDV infections. When considering how to manage BVDV problems, each case should be considered individually and particular attention paid to whether the herd is 'closed' or 'open' and the goals of the enterprise. Managing BVDV in a stud herd may be quite different from managing it in a commercial breeding herd, and control would differ again in a feedlot enterprise. Options for management include maintaining a closed, BVDV-free herd, vaccination of the whole herd to maintain a constant level of immunity in breeders, regular testing of the herd to monitor BVDV status, quarantine testing of all new animals imported onto the farm, or general acceptance of an endemic level of BVDV with no other intervention. The decision on the best choice for a particular enterprise must be made with the help of a veterinarian.

In a feedlot, the ideal prevention would be to induct only animals that have been vaccinated against BVDV infection. However, there is a school of thought that a vaccination with Pestigard at the time of induction still makes a difference to the incidence of BVDV. In a breeder herd, the aim is to either maintain a BVDV-free herd by careful biosecurity practices, quarantine and testing of new animals, or to accept endemic status and protect the breeding herd by vaccination. This usually takes the form of a vaccination program for heifers before their first mating, and then yearly, pre-mating for mature cows. The inherent danger is that after several years of rigorous vaccination of breeders, elimination of clinical disease, followed by a relaxation of the vaccination program, the entire herd becomes immunonaïve to the virus, with catastrophic consequences if the virus is introduced to the breeding herd.

Plant poisoning

This is included in this section on weaners and finishers, even though all cattle can be affected by poisonings, because young cattle tend to have a lower level of resistance to certain toxins and are inherently more curious than older cattle. However, plant poisonings are discussed here with reference to all groups of cattle. The plants listed below have been included in this chapter because they kill cattle or make them sick. Anecdotally, producers often suspect plant toxicity when faced with cases of sudden death in cattle. Excellent photographs are available in *Australia's Poisonous Plants, Fungi and Cyanobacteria* (McKenzie 2012). There are numerous plants that are in some way toxic to cattle. The toxic agent may not always be a chemical contained within the plant itself; it can be contamination of the plant with a toxic bacterium, parasite or fungus.

Paterson's curse

Paterson's curse (*Echium plantagineum*) is a major pasture weed throughout southern Australia and it is estimated that ~33 million ha are infested. It costs about $30 million annually to control Paterson's curse. The weed is also known as salvation jane, blueweed, Lady Campbell weed or riverina bluebell (MLA 2012c). The plant contains pyrrolizidine alkaloids which, when ingested by stock for extended periods, cause potentially fatal liver damage. Other families of plants also contain these toxins, including the Asteraceae (*Senecio* spp.), the Boraginaccaea (*Heliotropium* spp.) and Fabaceae (*Crotalaria* spp.) (Parkinson *et al.* 2010). The toxins damage the liver which then fibroses, and the liver becomes scarred and nonfunctional. By the time symptoms of toxicity become obvious the damage is often too severe to be reversed.

Clinical signs in cattle are varied and include depression, anorexia, diarrhoea, ill-thrift, wasting, jaundice, blindness, staggering and death (Peterson 1985; Parkinson *et al.* 2010; MLA 2012c). Blood tests can detect both the enzymes associated with chronic liver damage and the presence of pyrroles in the blood that definitively confirm the ingestion of pyrrolizidine alkaloids.

Treatment is to remove stock from the offending pasture but it may be too late to result in a recovery and animals that continue to deteriorate should be euthanased. Biological control strategies have been developed in Australia to manage the spread of this weed (Lehane 1991). MLA provides resources related to the weed (MLA 2012c).

Pimelea

Pimelea spp. are found throughout Australia but incidence of poisoning is mainly restricted to southern Queensland, northern New South Wales and northern South Australia. Plants in the genus include native riceflower, flaxweed and poverty weed; these are generally very unpalatable and are eaten by cattle as a last resort. This being so, toxicity occurs mainly in the summer months when land may have been overgrazed or where soil is not fertile and doesn't support perennial pasture.

Acute poisoning follows the growth of annual *Pimelea* spp. and causes severe, often fatal diarrhoea in cattle. Chronic poisoning (St George disease) is more common and cattle can be affected by ingesting the plants, or inhaling plant particles from decomposed dry plants. The toxins are simplexin or huratoxin and cause diarrhoea, ill-thrift, depression, neck oedema, increased respiratory rate and death after physical exertion (Pegg *et al.* 1994; MLA 2012c).

There is no treatment for affected animals and removal from infested pasture is the only way to manage the problem.

Kikuyu grass

Kikuyu grass (*Pennisetum clandestinum*) is an introduced perennial pasture that grows in spring and summer (Fig. 13.6). It is traditionally regarded as a good fodder for cattle because it is relatively high in energy and protein and maintains a firm hold in the soil, thus preventing excess erosion. There are large areas of grazing land in southern Australia where the main fodder source is

Figure 13.6: Kikuyu grass. Source: M. Laurence.

Kikuyu pasture. However, sporadic incidents of poisoning following grazing of Kikuyu pasture have been, and continue to be, reported (Gwynn *et al*. 1974; Bourke 2007; MLA 2012c).

The clinical signs of poisoning in cattle are variable and include drooling saliva, incoordination, abdominal pain, recumbence, depression, limb and tongue paresis, abnormal gait, coma and death. Signs usually appear one to eight days after animals have begun grazing toxic pasture; removal of animals from the pasture does not always result in recovery.

The mechanism of toxicity remains unknown. There are several theories but the firmer associations are with rapidly growing pasture in spring or autumn or after the application of fertiliser. Some have associated the presence of armyworm caterpillars and *Myrothecium* spp., *Fusarium* spp. and *Phoma* spp. of fungi (Ryley *et al*. 2007) with disease but no conclusive evidence of this is available (Bourke 2007).

Producers should be aware of the syndrome and look out for non-specific clinical signs in cattle, particularly after the recent introduction to lush Kikuyu pastures.

Bracken fern

Bracken fern (*Pteridium acquilinum*) is ubiquitous in Australia but grows particularly on poor infertile soils in coastal regions. It contains ptaquiloside, a noresquiterpene glycoside that is highly toxic for cattle. Poisoning occurs mainly during the dry season when there is a pasture deficit. Large amounts of the plant (leaf or rhizomes) must be eaten before clinical signs appear. The toxin causes both neoplasia and acute toxicity in cattle thus there are two forms of the disease, namely acute haemorrhagic disease and bovine enzootic haematuria.

Although all classes of cattle can be affected, it is usually weaners that suffer most. This disease commonly occurs in weaners after grazing bracken fern for between two and eight weeks. Bracken fern tends to grow on subfertile, sandy soils and when there is little other pasture for stock to eat they will eat bracken fern (Fig. 13.7). Weaners are inherently curious and will try new feed sources more readily than cows. The diseases are associated with depression in bone marrow activity and pancytopaenia thats leads to prolonged bleeding times. The

Figure 13.7: Bracken fern. Source: M. Laurence.

toxin also induces neoplastic changes in the cells that line the bladder.

Acute haemorrhagic disease is initially characterised by loss of condition, depression, marked pyrexia (up to 42°C), free blood in faeces, bleeding from the mucous membranes, and anaemia. Diagnosis is based on clinical signs and a history of exposure to bracken fern. Clinical pathology reveals pancytopaenia without regeneration and severely affected animals will die up to three weeks after they stop ingesting the plants. Less severely affected animals do recover.

Bovine enzootic haematuria is characterised by persistent blood in the urine. Long-term consumption of bracken fern over one to two years causes the disease in older cattle. Lesions are confined to the bladder and include mucosal tumours such as papillomas or haemangiosarcomas. These bleed persistently and result in a gradual loss of condition, anaemia, and ultimately death. There is no cure for animals where bladder tumours have developed.

Control relies on eradication of the ferns or ensuring that nutrition is adequate at all times as animals will not eat bracken fern in preference to normal pastures or hay. Fertilising with superphosphate allows strong pasture competition to suppress bracken fern growth. The best way to remove ferns is to physically uproot them but sprays are also effective.

Heart-leaf (1080)

Heart-leaf poison bush (*Gastrolobium grandiflorum*) is a woody perennial shrub that grows in bushland in central and western Australia and northern Queensland (Fig. 13.8). It has a preference for red, sandy soils and populates areas that are intermittently subject to water runoff. The leaves contain monofluoroacetic acid, also known as 1080 poison, that disrupts the citric acid cycle and energy metabolism. Ingestion of only a small number of these leaves invariably leads to a quick death (DPI 2011). Mass deaths have been reported in cattle, usually when they have broken through fences and grazed in woodlands on the edges of farms. Death is preceded by rapid onset of collapse, convulsions and respiratory paralysis and usually occurs with a day of ingestion of the plants. Affected animals are usually found dead. There is no treatment available.

Figure 13.8: Heart-leaf. Source: M. Laurence.

Ergotism

This disease occurs when cattle eat cereal grains that are contaminated with annual ryegrass (*Lolium rigidum*) seeds that are infested with the ergot (*Claviceps purpurea*) of rye, or endophyte (*Acremonium* spp.) infected grasses, notably tall fescue. It can also refer to poisoning by ergot (*Claviceps paspali*) of paspalum (Bourke 2000; DPI 2011). The infested ryegrass seeds are blackened and have the appearance of weevils or rodent droppings. Infected seed heads are said to be ergotised. The fungus contains a toxin that causes acute, peripheral, marked vasoconstriction and therefore normal temperature homeostasis becomes impossible. It also causes damage to blood vessels in the hooves. The disease manifests most commonly in feedlot cattle but can occur at any time that cattle food is supplemented with cereal grain (Peet *et al.* 1991).

Clinical signs usually present within 48 h of ingesting ergotised grain. The main sign is marked hyperthermia with core body temperatures exceeding 42°C. Associated with this is an increased respiratory rate, a clear nasal discharge, excessive salivation and inappetence (Fraser and Dorling 1983). Affected animals often attempt to stand in shade or in water troughs, and can become lame because the toxin induces laminitis by changing blood flow to the hooves. There is always very high morbidity (90%) but low mortality (<1%) and symptoms disappear quickly upon cessation of feeding contaminated grain.

Control is achieved by carefully examining cereal grain for evidence of ergotised ryegrass contamination before purchase.

Annual ryegrass toxicity

Annual ryegrass toxicity (ARGT) affects livestock grazing annual ryegrass (*Lolium rigidum*) seedheads that have been infected by the toxin-forming bacterium *Rathayibacter toxicus* (formerly *Clauibacter toxicus*). The bacteria adhere to nematodes (*Anguina funesta*) in the soil and enter the plants, with the nematodes, as they attempt to complete their life cycle. Bacteria colonise the seedheads, displacing the nematodes, and toxicity develops as the plants dry off (Kessell 2010). The toxin produced is corynetoxin, a potent neurotoxin (Cheeke 1995). Clinical signs are therefore normally seen between October and January but animals can suffer between March and July, particularly if their feed has been supplemented with meadow hay. Most cases have been reported in Western Australia and South Australia and it has been estimated that ARGT costs $40 million per year in Western Australia alone (Kessell 2010).

Clinical signs normally develop in animals about a month after they start grazing infected pastures. Death in cattle is relatively common and can happen as soon as a few hours after symptoms begin, but animals may suffer for several weeks yet not die. Stress often triggers disease and animals present with ataxia and incoordination, a wide foreleg stance and high stepping gait. Convulsions, opisthotonos and death follow in severe cases (McKay *et al.* 1993).

There is currently no treatment for ARGT. Affected stock should be mustered, quietly moved off affected pastures, and fed hay. A field assessment can often detect deformed heads, bacterial galls and maybe slime, but laboratory tests are required to quantify the levels present (Kessell 2010). Control relies on post-emergent herbicides to control ryegrass in cereal crops, grazing pasture hard while seedheads are still emerging (early spring), spray-topping to reduce ryegrass seed-setting and burning of affected pasture (Parkinson *et al.* 2010). There are biological controls that inhibit the movement of nematodes. The twist fungus (*Dilophospora alopecuri*) can be applied to pasture; this attaches to the nematode and inhibits its migration to the ryegrass seedhead. It has been commercially available since 1999 and needs to be used every year for five years for maximum efficacy.

Perennial ryegrass toxicity

This condition is also known as ryegrass staggers (RGS) and is one of the commonest causes of neurological disease in cattle. The disease is mainly seen in Victoria and southern New South Wales but it can occur anywhere where cattle are grazing perennial ryegrass (*Lolium perenne*) dominant pastures. About 90% of established perennial ryegrass plants are infected with the endophyte fungus, *Neotyphodium lolii*. This fungus lives in the leaf sheath and seedheads. The fungus is not harmful to the grass but it produces toxins (paxilline, lolitrem B, ergovaline and peramine) that are insecticidal and help it persist in pasture, and that can affect livestock.

The high-risk period is in autumn (Reed and Moore 2009) and animals that graze infected pastures can begin to show signs of intoxication after a few days. These include mild tremors, loss of coordination, a stiff gait, arched back, collapse, convulsions and death, although mortality rates are very low (Reed 2007). In an outbreak, most cattle in a mob may become affected but clinical signs disappear quickly when animals are removed from the source of the toxin. There are seldom persistent clinical signs and most animals recover fully.

Control relies on pasture management. Avoiding overgrazing and/or the build-up of leaf litter are two useful strategies. During the risk periods, animals need to be carefully monitored for the onset of clinical signs. Endophyte-free pastures are available but these tend to be less tolerant of insect pests and drought and can become contaminated with wild ryegrass in a few years.

Breeding cows

Breeding stock includes young heifers from the time they are weaned, primiparous heifers (first calvers) and mature cows. Each class of female has slightly different requirements and health issues. Heifers, for example, must be fed appropriately to allow for growth, the timely onset of puberty and the accumulation of sufficient bodyweight to fall pregnant, give birth to and rear a calf. First calvers must be managed to overcome the negative energy balance associated with rearing a young calf and to reduce the length of the post partum anoestrus interval. Management must also cater for the energy and protein requirements of an animal that is still growing (Chapter 14). This section will discuss some of the main animal health issues affecting the breeding herd.

Parasites

Breeding cows have a better developed immune system than weaners but are still at risk of various kinds of parasitism. Intestinal worms and flukes are still a concern, particularly in heifers and first calvers, but these were addressed above. This section will consider external parasites, the most important of which are ticks.

Ticks

Sackett *et al.* (2006) described the direct and indirect effects of cattle tick, *Rhipicephalus (Boophilus) microplus*, as the most serious animal health concern to the beef industry in Australia (Table 13.2). Production loss associated with meat loss (i.e. failure to thrive) has been estimated at $63 million per year and mortality from tick-related illness costs $28 million per year. Efforts to control and manage ticks associated with the costs of labour, chemicals and other husbandry strategies have been estimated to cost over $41 million per year (McLeod 1995). Others have estimated a total cost to the beef industry of $146 million per year (Sackett *et al.* 2006).

Ticks populate the northern regions of Australia above a line extending from approximately Broome in Western Australia (17.9620°S, 122.2360°E) to Brisbane in Queensland (27.47278°S,153.02778°E). This line is the rough equivalent of the 19th parallel of south latitude (Fig. 13.9).

Ticks cause production loss in two main ways. Heavy tick infestations can on their own cause tick worry, which is associated with production loss through weight loss, hide damage and death from anaemia (Gee *et al.* 1971; Jonsson *et al.* 2008). Heavy tick burdens can cause anaemia to the point where cattle will die if left untreated. The extent of the anaemia caused by ticks can be partly mitigated by good nutrition. Heavy tick burdens also reduce voluntary feed intake, that in turn reduces growth rates. There is evidence to suggest that heavy tick infestation depresses the host's immune system (Ferreira and Silva 1998) and makes it more vulnerable to protozoan parasite infections and other infectious diseases. Heavy burdens have been variously defined as between 150 and 330 engorged ticks per cow (Jonsson 2006). A damage coefficient has been used in the past (Sutherst *et al.* 1983) to estimate the production loss per engorged female tick. A review of 19 studies reports that, on average, one engorged tick caused 1.18 ± 0.21 g bodyweight per day loss in *Bos indicus* cross cattle and 1.37 ± 0.25 g bodyweight in *Bos taurus* cattle (Jonsson 2006). The current total estimated loss of beef is 6594 t per year, which is modelled to increase to 7780 t peryear by 2030 with predicted changes in climate (White *et al.* 2003).

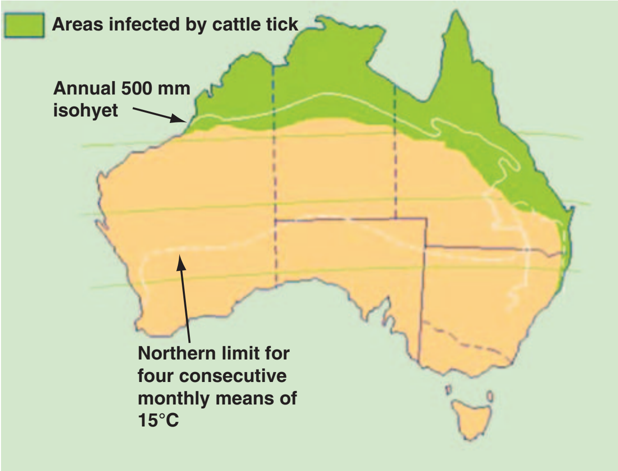


Figure 13.9: Map of Australia showing the tick line. Source: After Sackett *et al.* (2006).

Ticks are also vectors for the intracellular protozoan parasites in the genera Babesia and Anaplasma. These parasites cause illness and death in cattle throughout the north of Australia.

It is well known that *Bos indicus* cattle have a stronger immune response to ticks and carry fewer ticks than *Bos taurus* cattle. Purebred Brahmans generally carry one-tenth the number that Herefords would carry if exposed to the same infestations (Jonsson *et al.* 2008). Cattle with at least 50% *Bos indicus* content are up to 10 times more resistant to ticks than pure *Bos taurus* cattle.

Control of ticks is feasible, eradication of cattle tick is not. The control measures that are employed on a property are specific to location, time of year and breed. In designing strategies to control ticks, a producer can choose one or several of the following broad categories of tick control measures.

Acaracides are chemical, usually organophosphates, synthetic pyrethroids or macrocyclic lactones that are applied to cattle in dips or as topical preparations. There is widespread resistance to many of these chemicals and their use is becoming less effective as resistance increases (Foil *et al.* 2004).

A tick vaccine called Tickgard® (Intervet Australia) worked by destroying the tick's gut after it had fed on cattle, thereby reducing cattle tick numbers (AVJ 2002), but it is no longer commercially available in Australia. A vaccine containing the same antigen is sold under the trade name Gavac® in Cuba.

Protozoan and rickettsia parasites

The prevalence of anaplasmosis, caused by *Anaplasma marginale*, appears to be increasing. *Anaplasma* is an intracellular rickettsial parasite that parasitises the red blood cells of cattle. It occurs mainly in autumn and winter in the tropical and subtropical tick-infested and adjacent regions. The disease is spread by the cattle tick or blood-sucking arthropods, but blood-contaminated surgical instruments can also transfer the organism. The severity of infection increases with age and the prevalence is much higher in cattle three years of age and over, although it has been recorded in younger cattle including calves. Calves generally have a level of maternal immunity that protects them from the disease. *Bos indicus* cattle are much more resistant to the disease than *B. taurus* breeds (AVJ 2002; Jonsson 2006).

The disease is characterised by ill-thrift and slowly progressive anaemia that eventually becomes severe. Other symptoms include anoxia and weakness, pyrexia, a rapid respiratory rate, increased heart rate and jaundice in severe cases. It is associated with a moderate level of mortality.

Treatment is possible with injections of oxytetracycline (22 mg/kg IM for three to five days) but vaccination with a combined live vaccine for *Anaplasma marginale*, *Babesia bovis and Babesia bigemina* is the best form of control. The vaccine uses the less virulent and non-tick-transmissible organism *Anaplasma centrale* and is available, combined with *Babesia* organisms, from the Tick Fever Centre, of the Department of Primary Industries and Fisheries, Queensland.

Babesiosis, commonly known as tick fever, is caused by *Babesia bovis* and *Babesia bigemina.* This disease causes significant economic loss of approximately $16.9 million per year through mortality, abortions, lost milk and meat production and through ill-thrift throughout the tropical and semi-tropical regions of the world (Bock *et al*. 2004).

Again, the disease does not occur in calves as they acquire immunity in utero as well as from colostral antibodies. This immunity lasts about four to nine months in the calf and adults become susceptible from nine months to three years old. It has been well demonstrated that *Bos indicus* have a higher degree of innate resistance to babesiosis than *Bos taurus* animals (Johnston and Sinclair 1980; Bock *et al.* 1999).

The protozoan parasite has the tick as one of the intermediate hosts. In cattle, the parasites replicate in red blood cells and cause cell lysis and a severe inflammatory response that is one of the causes of the severe clinical signs. Cytokines and other inflammatory mediators that are released as part of the immune response cause vasodilation, capillary permeability, vascular collapse, coagulation disorders and circulatory status. The worst clinical signs are associated with acute disease and include marked pyrexia (up to 42°C), increased respiratory rate, severe anaemia, jaundice, abortion, diarrhoea, haemoglobinuria, haematuria (red urine), nervous symptoms, coma and death (Jonsson *et al*. 2008).

Cattle normally get babesiosis if they:

- have been recently moved from a tick-free to a tick-infested area;
- are in a marginal tick area where tick numbers have been low for some time and are exposed to high tick burdens for some reason.

Treatment is possible using Diminazene and Imidocarb. It must be noted that Imidocarb will interfere with the generation of adequate immunity after vaccination.

Treatment with either of the above-mentioned drugs will provide short-term protection, which can be useful if cattle are being moved into an infected zone. Animals that recover may become carriers for life.

For herd protection, or for larger numbers of cattle being transported into tick areas, vaccination with the combined live vaccine is indicated. Some reactions to the vaccine may occur within six to 14 days. Cattle vaccinated once with a live vaccine containing *B. bovis* and *B. bigemina* will develop long-lasting immunity.

Theileriosis is a tick-borne infectious disease. This disease is caused by *Theileria* species, which are intracellular apicomplexan parasites that affect a range of domestic and wild animals, particularly ruminants (Islam *et al*. 2011; Kamau *et al*. 2011). For many years a relatively benign form of the disease was attributed to infection with *Theileria buffeli*, recently assigned to the *Theileria orientalis* group, but there are now reports of a far more serious syndrome associated with infection with the *ikeda* and *chitose* genotypes of *Theileria orientalis.*

Benign theileriosis has traditionally been associated with no clinical signs but the more severe form of the disease (east coast fever), which does not occur in Australia, has been shown to cause fever, anaemia, jaundice, depression, abortion and death. Drugs effective against *Theileria* spp. include primaquine, halofuginone and buparvaquone, but they are not registered in Australia for use in cattle (Izzo *et al*. 2010).

Buffalo fly

Buffalo fly (*Haematobia irritans exigua*) occur in northern Australia, Queensland and the northern areas of New South Wales but can spread south depending on climatic conditions (Williams *et al*. 1985). Buffalo fly irritation and the cost of controlling infestations costs beef producers nearly $80 million per year (Sackett *et al.*

2006) at an estimated cost of $30/head (MLA 2003). It remains the second most important animal health problem facing the beef industry in Australia and causes major problems for cattle in marginal areas that don't have any natural resistance to the fly. Buffalo flies live permanently on the host in large colonies and feed 10–40 times per day on blood. This can cause significant blood loss.

Bulls and dark-coated cattle often carry heavier fly burdens. Some cattle are 'allergic' to buffalo flies and are intensely irritated by as few as four or five flies. These cattle scratch and rub themselves constantly, which results in large sores on their necks and sides. The value of the hide is reduced when cattle have developed skin sores as a result of buffalo fly infestation.

The flies are active in summer and early autumn. Optimum egg-laying temperatures are 25–35°C. In extensive areas, problems include access to cattle for treatment during the wet season. Cattle crossed with *Bos indicus* have higher innate levels of immunity to fly infestations.

Control relies on a combination of chemicals (Table 13.9), fly traps and backrubbers that apply insect repellent when cattle walk under them. Flies are developing increasing resistance to synthetic pyrethroids, one of the main classes of chemicals used in buffalo fly control (Rothwell *et al*. 2011). Dung beetles are used to control manure build-up and limit the breeding sites for flies (Flynn 2001; Spence 2007).

Bovine ephemeral fever

Bovine ephemeral fever (BEF), also known as three-day sickness, costs Australian producers $101 million per year (Sackett *et al*. 2006). The disease is caused by an arthropod-borne virus in the Rhabdoviridae family. It is postulated that the vector for the disease is mosquitoes that are members of either the genus *Culex* or *Anopheles* mosquitoes, or biting midges from the genus *Culicoides* (Parkinson *et al*. 2010). The disease occurs in outbreaks where these vectors are known to occur and in summer and autumn when they are most active. There is also a well-recognised association between periods of heavy rainfall followed by warm weather (Kirkland 2002). Affected animals are usually less than two years of age.

About six days after infection, the disease causes biphasic fever spikes with body temperatures peaking at 41°C for a 12 h period. The initial fever is followed by a slow decline then another sharp rise in temperature 12 h later. Day 2 of the illness is associated with inappetence, reluctance to move, hypersalivation, limb stiffness, ocular and nasal discharge, shifting lameness, submandibular oedema and occasionally pulmonary emphysema. Up to 5% of pregnant cows will abort owing to the high fevers (Kirkland 2002). Bulls will become infertile for up to six months (Uren 1989). Heavy bulls can suffer from myonecrosis from lying down for extended periods. This will sometimes render them unable to rise, in which case they have to be euthanased. Deaths in cattle are unusual but there is loss in production associated with abortion, decreased milk production, loss of gain in feedlots, and infertility in bulls.

Diagnosis is mostly on the basis of clinical signs, namely the sudden onset of dullness and listlessness in several animals in a herd followed by recumbence and the other clinical signs. The brevity of the disease is also a key

Table 13.9: Chemicals available for the control of buffalo fly

Treatment	Method	Meat withholding
Organophosphate (OP)		
Diazenon – Patriot (Zoetis)	Eartag	Nil
Chlorfenvinphos – Supona (Zoetis)	Spray, backrubber	Nil
OP and synthetic pyrethroid		
Barricade S (Key Industries)	Dip and spray	8 days
Synthetic pyrethroids		
Deltamethrin – Coopafly (Coopers Animal Health)	Spray	Nil
Cyalothrin – Grenade	Plunge dip	Nil
Pour-on		
Ivermectin 21-day control	Back-line	42 days
Starbar – insect growth regulator (IGR)	Bolus	

Source: MIMS (2011).

diagnostic feature. Treatment is not normally required, but treatment with non-steroidal anti-inflammatories and provision of water, food and shade may be warranted in valuable cattle. Treatment should be started at the first sign of illness.

There are several forms of live-attenuated, inactivated and recombinant vaccines available in Australia but these have variable efficacy and durability of protection (Walker 2005). The decision to vaccinate animals depends on the predictability of outbreaks and the value of animals. Vaccination is usually restricted to bulls, stud animals and animals from non-endemic areas. Animals that have had BEF develop a lifelong immunity to the disease. To avoid vaccination failure, it is essential to follow the label instructions with regard to the two inoculations for the primary vaccination.

The National Arbovirus Monitoring Program (NAMP) monitors the spread of ephemeral fever virus within Australia.

Bovine Johne's disease

Bovine Johne's disease (BJD), also known as paratuberculosis, is a disease of ruminants characterised by chronic diarrhoea and progressive weight loss. The disease has a worldwide distribution, and ~22% of dairy and 8% of beef herds in the USA are infected. Johne's disease (JD) also affects goats, sheep, bison, camelids, farmed deer and elk, and other domestic, exotic and wild ruminants. In Australian cattle, it is endemic and mostly affects south-eastern dairy populations, but it can occur in beef cattle and remains a notifiable disease. There is a postulated, but unproven, link with Crohn's disease in humans, resulting in a renewed focus on the epidemiology and control of BJD.

BJD is caused by *Mycobacterium avium* subsp. *paratuberculosis* (MAP), a slow-growing anaerobic, acid-fast bacterium. It was recently classified as a subspecies, and some texts refer to it as *M. paratuberculosis*. Like other pathogenic mycobacteria, MAP can survive and replicate within macrophages. It can survive outside the host for long periods (nine to 18 months), especially in cool, damp conditions, but is vulnerable to some disinfectants, direct sunlight and heat, making it less of a problem in the north.

Infection can be horizontal (animal to animal) or vertical (dam to foetus in utero). Most animals become infected in the first few weeks of life through ingestion of organisms from the faeces or milk of an infected cow, usually their own dam. Faecal contamination of teats, udders and the calving environment are the most important sources of infection. Infected cows can shed the organism in colostrum and milk. Approximately 35% of symptomatic cows and 3–20% of asymptomatic cows shed MAP in their milk, and twice as many shed the organism in colostrum. In utero transmission occurs in 20–40% of cows with clinical disease and in 8% of asymptomatic cows. Introduction of disease into an uninfected herd is almost always due to purchase of asymptomatic infected animals. Resistance to infection increases with age. Only a small dose of organisms is required to establish infection in neonatal calves, but a massive dose is needed to infect adults.

After ingestion, MAP is phagocytosed by and proliferates in macrophages of the distal small intestine and the regional lymph nodes. Huge numbers of macrophages are recruited to the site of infection and infiltrate the intestinal mucosa. This results in slowly progressive diffuse granulomatous enteritis and, years later, clinical BJD.

The stages of infection are:

Stage I – 'silent' infection. Calves, heifers and young stock infected with MAP but with no clinical signs of disease (typically all infected animals <2 years of age);
Stage II – subclinical disease. Infected adult cattle have no clinical signs of disease. These animals may be more prone to other diseases such as infertility and mastitis, and are often culled from the herd before BJD is diagnosed;
Stage III – clinical disease. After the long incubation period, infected cattle develop gradual weight loss, chronic, intermittent diarrhoea and decreased milk production.
Stage IV – advanced clinical disease. Animals become increasingly cachectic and lethargic, and develop pipestream diarrhoea. They eventually die from dehydration and cachexia if they are not culled. Most cases become clinically apparent between two and six years of age, and disease before two years is rare.

Treatment is rarely indicated because it is protracted and expensive. It is occasionally requested for animals of exceptional genetic value or companion animals. Treatment is not curative, but it can delay disease progression. Affected cattle continue to contaminate the environment heavily.

Squamous cell carcinoma of the eye

Ocular squamous cell carcinoma (OSCC), or eye cancer, is the most economically important eye disease of adult cattle in susceptible breeds (Watt 2006). Australian

Quarantine Inspection Service (AQIS) abattoir figures (August 2002–August 2003) indicate that 22% of total condemnations in mature cattle and 7.3% of condemnations in cattle younger than four years of age are due to eye cancer. Overall, eye cancer represents 47% of all cancers that result in carcass condemnation (DPI 2004). A survey of beef herds in Australia reported the prevalence of OSCC to be 10–20% in all beef herds (Spradbrow *et al*. 1977).

There is a definite breed predisposition to this condition. Cattle with apigmented periorbital skin are at greater risk. OSCC has been diagnosed in Holstein-Friesian, Holstein, Hereford, Simmental, Guernsey, Shorthorn, Ayrshire, Brahman, Brown Swiss, Hollandensa, Javanese-Mongolian, Jersey and Normandy breeds of cattle (Tsujita and Plummer 2010). The major losses occur because of reduced selection opportunities in replacement heifers that lack eye pigment and the early culling of breeders affected with OSCC.

This is an important disease because the Hereford breed is common in temperate Australia and Simmentals have become a commonly utilised European breed for crossbreeding. The prevalence increases with increasing distance from the equator and with increased altitude. It increases with age and is most common in cattle over five years old.

OSCC results from the effects of cumulative damage of UV radiation on unpigmented skin (eyelids) mucosa (third eyelid) and unpigmented sclera. A papilloma virus has been isolated from precursor lesions but its significance is unknown (Tsujita and Plummer 2010). OSCC occurs on the eyeball at the corneo-scleral junction at either the medial limbus, or more commonly the lateral limbus site. OSCC starting from these sites can engulf the whole eyeball, adjacent orbital tissues and finally, on rare occasions, encroach on the brain. Early lesions show as white circumscribed plaques that may develop into active spreading red fleshy tissue involving the cornea and bulbar conjunctiva.

It can also occur on the eyelids, particularly the unpigmented skin and lower eyelids. Initial eyelid lesions begin as dark brown horn-like keratomas. These may then develop into bulky OSCC lesions 1–8 cm in diameter. Lesions are commonly found on the third eyelids and always start on or close to the centre of the free edge (Fig. 13.10). The disease soon spreads through the third eyelid to the medial canthus. It is important to detect and treat the disease as soon as possible, because often the orbital bone becomes affected as the disease advances.

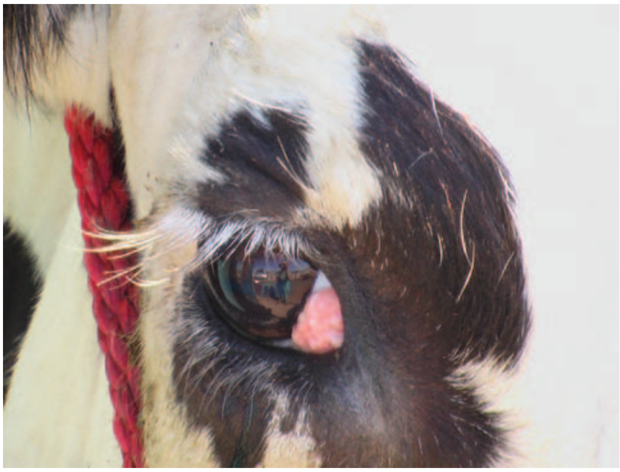


Figure 13.10: Advanced SCC of the third eyelid in a dairy cow. Source: M. Laurence.

Prevention relies on selection for eye pigmentation within the breed. Crossbreeding with a dark-faced breed such as Angus, Red Shorthorn or Limousin is advantageous.

Treatment options depend on the severity of the lesions and can include surgical removal of the lesion or the whole eye, cryotherapy for small lesions, radio and immunotherapy. OSCC can be very painful and is always associated with blepharospasm, inflammation and eye discharge. This disease impinges on the animal's welfare and when it is diagnosed animals should be treated or culled immediately. The lesions never resolve and are always progressive. Producers should carefully determine if an animal is fit to load before transportation to meat works, especially as cattle with secondary metastatic lesions are automatically condemned at slaughter (Williams 2010). It is regarded as an offence under state laws, e.g. the *Prevention of Cruelty to Animals Act* (NSW 1979), to allow eye cancer to develop to the advanced stages, and owners failing to cull such animals early enough may face prosecution.

Bulls

The dairy industry in Australia has broadly adopted the use of artificial insemination (AI) as a technique for breeding cows, but the beef industry still relies heavily on natural mating. Careful selection of bulls is vital, particularly because 87% of the genetic composition of the breeding herd in a closed system is associated with the last three generations of bulls. Managing bulls and looking after their health relies on the basic principles of supplying adequate nutrition (Chapters 14, 16), choosing the most appropriate bull for the target market through the use of powerful genetic selection tools such as BreedPlan

(Chapter 17) and ensuring that the chosen bull is fit for use through examination of his structure, semen quality and ability to serve (Chapter 14). There are a few diseases that are specifically associated with bulls, such as bovine venereal campylobacteriosis and trichomoniasis; these too are covered in Chapter 14.

Bulls suffer more from disease associated with injury, usually limb injury or injury to the external genitalia, and lameness owing to their size, the physical requirements of mating and the tendency to fight. A marker for polledness (absence of horns) in cattle has been identified (Prayaga 2007; Mariasegaram *et al*. 2012) and these authors suggested that in Australian Brahman cattle it could potentially be used as a diagnostic marker in *Bos indicus* cattle. The Beef Cooperative Research Centre has released an Australian poll gene marker test which allows for selection for cattle without horns, including for *Bos indicus* cattle (CRC 2012). This will help to minimise injuries and bruising of tissues when animals are in yards or transported.

Careful monitoring for injuries and lameness and rapid consultation with a veterinarian will always give the best chance of a successful treatment or a timely insurance claim.

Exotic diseases

Australia is in the fortunate position of being geographically isolated. Our closest neighbours in Asia are archipelagos of islands that themselves have natural perimeter biosecurity, namely the ocean. But there are significant exotic diseases that pose a threat to the cattle industry and producers need to be ever-vigilant in their surveillance for and protection against the introduction of these diseases. This section briefly discusses the diseases of most significant concern to the beef industry in Australia.

All exotic disease is notifiable. A notifiable disease is one that must immediately be reported to agricultural authorities. In Australia there is a Disease Watch Hotline where the public can report suspected exotic diseases (DAFF 2013).

Foot and mouth disease

Foot and mouth disease (FMD) is the exotic disease that poses the greatest risk to the agricultural industry in Australia. It is estimated that in the event of an FMD outbreak, the disease could cost Australia as much as $16 billion. This is based on a worst-case scenario of a 12-month outbreak spread across a large area (Entwistle and Fordyce 2003).

FMD is a highly contagious vesicular disease of cloven-hoofed animals. The disease causes erosive lesions on the tongue, dental pad, feet and mucous membranes of animals. The lesions are extremely painful and debilitating and although affected animals seldom die, they suffer greatly for extended periods. Growth and reproduction are severely compromised and recovered animals will invariably fail to achieve all production targets, whether milk production, calf production and rearing or growth for meat production. FMD has such a massive economic impact owing to the cost of loss of production as well as the cost of eradicating the disease, loss of export revenue until disease-free status is restored and subsequent surveillance. FMD is spread by direct contact, by birds, or via fomites such as tyres or trucks.

Treatment is never indicated and affected animals are usually euthanased. Control depends on destroying all infected animals, with or without a vaccination program for neighbouring properties. In Australia, Animal Health Australia publishes an FMD disease strategy outlining the response in the event of an outbreak (AHA 2012b). Recently, a review by Mathews (2011) discussed Australia's preparedness for such an outbreak.

Bluetongue

Bluetongue is an arthropod-borne viral disease of ruminants. Exposure to bluetongue virus is widespread and occurs in many parts of the world including countries in Africa, Europe, the Middle East, India, Mexico, the USA, South-East Asia and northern Australia. Bluetongue virus can only exist and spread if species of *Culicoides* midge is present. These insects are most active during warm summer months and are responsible for the spread of bluetongue virus from animal to animal. Severity of the disease depends on the serotype, or strain of the virus (Maclachlan *et al*. 2009).

Although the *Culicoides* spp. midges that spread the bluetongue virus are present in northern Australia and the virus is therefore spread to cattle, infected cattle do not show clinical signs (Melville and Pinch 2003). Only six of the 180 *Culicoides* currently known midge species in Australia are capable of spreading bluetongue virus (Parkinson *et al*. 2010). These six species live primarily in the north of Australia. The virus is spread when the midges feed on cattle. Sheep are considered a spill-over host and do not generally reside in northern endemic bluetongue virus climatic zones.

In other countries, some serotypes of the bluetongue virus in cattle can cause mild clinical illness. There is usually illness in <5% of the herd and it can include a mild fever, catarrhal inflammation and erosions on the mouth and nasal cavities. Occasionally, mild lameness and a stiff gait are associated with bluetongue virus infection (Blowey and Weaver 2003).

The diagnosis of clinical bluetongue in Australian cattle would have a serious impact on the live cattle export industry (Chapter 12). Many countries that import Australian cattle would cease trading were there to be confirmed cases of bluetongue in Australia. Therefore, the Australian government is dedicated to ensuring Australia's disease-free status and monitoring for new infections. The National Arbovirus Monitoring Program (NAMP), which is managed by Animal Health Australia, is responsible for monitoring bluetongue virus occurrence and spread in Australia, particularly the north/south interface. The changing range of the virus zone is published each year on the NAMP website (NAMP 2012).

The NAMP uses sentinel herds of young cattle to determine if cattle are being infected with bluetongue virus and if there is any illness associated with it. Exposure to the virus has been detected in sentinel herds but no illness has been detected (Melville and Pinch 2003). Herd and flock surveillance for bluetongue virus-related illness is an ongoing process across Australia. The NAMP also uses light traps to monitor the distribution of *Culicoides* spp.

Screw worm

Old World screw worm fly (OWSWF) (*Chrysomya bezziana*), is an obligate parasite of warm-blooded animals. The flies live in many countries and Australia is particularly at risk because of the presence of OWSWF in Papua New Guinea and Indonesia.

Adult flies lay eggs in open wounds; within a day the eggs hatch and the larvae feed on the open wounds. Infected wounds become large, inflamed, suppurative and painful, and do not heal. These symptoms cause serious loss of production. Animals whose wounds become reinfected, as is frequently the case, often eventually die. Animal Health Australia publishes an SWF disease strategy that outlines the response in case of an outbreak (AHA 2007).

The New World screw worm fly (*Cochliomyia hominivorax*) occurs in the Central American tropics and is not considered a similar risk for Australia.

Other exotic diseases

Other diseases that pose a danger to beef cattle production in Australia include bovine brucellosis, lumpy skin disease, peste-des-petits ruminants, rinderpest, vesicular stomatitis, rabies, surra and Rift Valley fever. A national response plan for each of these is outlined by Animal Health Australia (AHA 2013).

ANIMAL WELFARE AND LOW-STRESS ANIMAL HANDLING

Philosophy of animal welfare and low stress handling

The book *Animal Liberation* (Singer 1976) argued that the ethical ground for choosing one action over another was always to serve the greatest good for the greatest number. Singer said that to exclude animals from this ethical judgment was what he called 'speciesism' – discrimination on the grounds of species, comparable to discrimination against people on the grounds of race (racism) or sex (sexism).

Singer (1976) argued that among the important human interests are avoiding pain, developing one's abilities, satisfying basic needs for food and shelter, and being free to enjoy close personal relationships. He suggested that the fundamental factors that entitle any being, human or non-human, to equal consideration are the capacity for suffering and the capacity for happiness and enjoyment.

The capacity for suffering is shared by all sentient creatures, the definition of sentient being 'to have the power of perception by the senses', from the Latin verb sentire, 'to feel'. While it is not yet possible to measure such refinements of feeling as grief or loss or longing, either in humans or in other animals, it is commonplace that the basic sentient capability of most animals far exceeds that of human beings: they see better, they hear better, they smell better and they can discern more with their sense of touch. There is also vast anecdotal evidence that animals have and use other senses apart from the fundamental five, and that these abilities are still a mystery to scientists.

If sentience is the criterion for treating creatures with consideration, then animals apart from humans clearly qualify.

The so-called 'five freedoms' necessary for animal welfare were developed in 1979 by the UK Farm Animal Welfare Council (FAWC 1979). In the western world they have been widely incorporated into the guidelines of organisations influential in regulating the handling of animals.

Paraphrasing the UK Farm Animal Welfare Council, the EU policy defines the five freedoms as follows (EUD 2012):

- freedom from hunger and thirst – which means access to fresh water and a diet for full health and vigour;

- freedom from discomfort – animals are entitled to an appropriate environment, with shelter and comfortable rest areas;
- freedom from pain, injury and disease – implying human action in prevention or rapid treatment;
- freedom to express normal behaviour – with adequate space and facilities, and suitable company;
- freedom from fear and distress – so that they do not suffer from the prospect of stressful conditions and treatment.

This notion is no longer treated as revolutionary, but has legal definition in Australia through the state Acts governing the standards and guidelines for treatment of animals. Under the Australian Animal Welfare Strategy (http://www.australiananimalwelfare.com.au/) it is expected that a coherent federal animal welfare policy will be developed, resulting in a federal act to replace the separate state laws. The first step has been the enactment of the land transport of livestock standards and guidelines late in 2011, following by the promulgation of individual state regulations under the Act during 2012.

Invoking the status of the law signifies that the background ideas are already accepted by the general public. In short, in Australia and in much of the rest of the western world, it has become accepted that to treat animals well is, for ethical and philosophical reasons, the right thing to do. It also makes sense from a safety and economic point of view.

Stressed animals are difficult and dangerous to handle, and the more stressed they are the more stressed the handlers become, especially if they lack expertise and the correct infrastructure for handling animals. When animals and handlers are stressed there is increased likelihood of injury to either the animals themselves or to the handlers through accident or outright attack. The most effective insurance against injury is adequately training people in the low-stress handling of animals.

Cattle are herd animals, and also prey animals. If an individual is separated from the herd its vulnerability to attack by a predator is heightened and it is immediately liable to panic, triggering a fight-or-flight response. In these circumstances a person is perceived as a predator, and training of stock handlers takes into account this predator–prey relationship.

Recognising the ‘flight zone’ of the herd or an individual (the distance between handler and animal within which the animal will move away from the handler) and the ‘point of balance’ (the point on the side of the animal’s body in front of or behind which the handler positions themselves to cause the animal to move either backward or forward) enables the handler to maintain a safe working distance from the animal.

Safety for the herd, when allowed to move quietly and without panicking, thus ensures the safety of the handler. Stock handlers who abide by this principle know that hurrying animals invariably means that the job will take longer. Mustering, loading, moving a herd from one pasture to another, unloading, separating one or some animals from the rest – all need to be done slowly and quietly, with a minimum of background noise, no whip-cracking or shouting, no barking dogs. Cattle’s sense of hearing is acute, and loud noise frightens them.

Because sudden, fast movement can also panic a herd, walking slowly, keeping arm movements to a minimum, every day among the herd accustoms the herd to the unthreatening presence of the handler. The cattle become familiar with the handler, the flight distance shrinks, and directing the cattle becomes easier.

Low-stress handling of cattle

MLA (2013) gives some simple guidelines for stock handlers. Livestock handling should aim to minimise stress for the livestock and the operator. Livestock and operator health and welfare are of prime concern; however, handling can also affect animal performance and meat quality (Chapter 2). Successful handling of livestock requires an understanding of their natural behaviour.

Low-stress cattle handling has productivity benefits for farming enterprises. It will deliver improved livestock health and production, and better meat quality to the customer. It will also improve occupational health and safety. Stress is likely to be minimised by:

- keeping animal handling to the minimum level necessary for health management and productivity, e.g. using remote measurement technologies associated with precision animal management can help achieve this (Guerin 2013);
- designing handling facilities to minimise the risk of injury and to take advantage of natural cattle, sheep or goat behaviour;
- maintaining handling facilities in good working order and completing repairs well before major husbandry practices are carried out;
- ensuring livestock handlers are trained or experienced and competent;
- avoiding sudden jerking movements and loud noises;
- behaving in a calm and controlled manner;

- applying optimal pressure rather than excessive pressure by taking advantage of the flight zone (livestock that are not familiar with people have a larger flight zone than livestock handled more often);
- calmly speaking to livestock while working with them can have a calming effect (not shouting, yelling or making other sudden loud noises);
- avoiding rushing livestock, giving them time to assess a situation;
- using dogs carefully (muzzle dogs that bite and tie them up when they are not working);
- preventing overcrowding in confined spaces;
- avoiding handling livestock during extreme weather conditions.

Changes in diet and water supply are also stressful for livestock, increasing the risk of weight loss and dehydration and susceptibility to disease. Changes need to be carefully planned and introduced gradually. Producers should try to avoid major changes in diet and water supply at the same time as other stressful husbandry procedures are being carried out.

As consumers become more aware of the conditions in which animals are reared and ultimately slaughtered, they are demanding to know that those conditions conform to the five freedoms, so far as it is practicably possible for human beings to ensure them. The economic self-interest of producers is served by optimising the welfare of the animals in order to optimise production and retain their share of a more aware market.

Law-makers do well to lay the responsibility for injury, pain and hardship suffered by animals destined for slaughter on owners or breeders, handlers involved in loading and unloading, animal transport companies and their truck drivers, and owners and staff of the abattoirs. It is likely that when every person who has contact with production animals carries their share of responsibility for animal welfare from birth to death, the number of animals hurt or that die in transit decreases, as does the wastage of meat spoiled because of bruising or dark-cutting (the change in meat colour resulting from the depletion of muscle glycogen stores; Chapter 2). Producers trading over-the-hooks on beef carcass specification have experienced price discounts of 5–20% of carcass weight for dark-cutting beef (Littler and House 2001). Each person who suffers financial loss if animals are injured or die between the farm or feedlot and the abattoir will strive to play their individual part in ensuring the best possible conditions of transport and slaughter.

Several authors have written on the topic of cattle behaviour and animal welfare (Phillips 1993, 2002; Fraser 2008; Houpt 2011; Webster 2011). Among them is Temple Grandin, a respected academic, best-selling author and consultant to the livestock industry on animal behaviour, who said:

> I think using animals for food is an ethical thing to do, but we've got to do it right. We've got to give those animals a decent life and we've got to give them a painless death. We owe the animal respect.

Her website (http://www.grandin.com/) about livestock behaviour, design of facilities and humane slaughter, is recommended to anyone interested in animal welfare. It covers such topics as:

- design of stockyards, corrals, races, chutes and loading ramps;
- non-slip flooring for livestock handling;
- design of restraining systems;
- humane slaughter;
- stress and meat quality;
- ritual slaughter (kosher and halal);
- guidelines for auditing welfare in slaughter plants, beef feedlots and dairies;
- surveys of stunning and handling in slaughter plants;
- animal welfare and rights.

Much of what she has to say is simple common sense, for instance that crowd pens should be level, and that animals should be able to see two or three body lengths into the chute before it curves (Grandin's chutes are curved because cattle move most naturally if they perceive that they are going back to where they came from) so that they have the impression they can see where they are going. She suggests keeping numbers of animals in a crowd pen down to about half the capacity of the pen (she favours handling cattle in small groups at all times and in all environments), giving them room to move easily and quietly to minimise the risk of panic, stampede, falling and other injury to themselves, one another or handlers. Non-slip flooring throughout is an obvious aid to safe movement (MLA 2012a).

She stresses that cattle don't like to move from bright light into the dark, or to move towards bright light, and suggests the use of skylights in indoor facilities to minimise sharp contrast of light and dark. Her chutes and yards have solid sides so that distracting objects and movement outside are not visible, especially people who may be standing deep within the animals' flight zone.

Grandin (1994) makes the point that:

> After adequate equipment has been installed, the single most important determinant of good animal welfare is the attitude of management … Places where animal welfare is poor often have a manager who does not care. A good manager enforces standards to maintain good welfare. Employees are well trained and people who abuse animals are punished. I have observed that the most effective manager is involved enough in day to day operations to care but he or she is not so involved that they become numb and desensitized to animal suffering. People who handle hundreds of animals each day can become desensitized. They need a strong manager to serve as their conscience.

REFERENCES

AHA (2003a) Biosecurity or disease risk mitigation strategy for the Australian cattle industry. *Farm Biosecurity*. <http://www.farmbiosecurity.com.au/files/2011/04/Cattle-Farm-Biosecurity-Plan.pdf>.

AHA (2003b) Biosecurity plan Australian lot feeding industry. *Farm Biosecurity*. <http://www.farmbiosecurity.com.au/files/2011/04/Lot-feeding-Farm-Biosecurity-Plan.pdf>.

AHA (2007) Disease strategy: screw worm fly. *Animal Health Australia – AUSTVETPLAN*. <http://www.animalhealthaustralia.com.au/programs/emergency-animal-disease-preparedness/ausvetplan/disease-strategies/>.

AHA (2012a) Bovine Johne's disease in Australia. *Animal Health Australia*. <http://www.animalhealthaustralia.com.au/programs/johnes-disease/bovine-johnes-disease-in-australia/>.

AHA (2012b) Disease strategy: foot-and-mouth disease. *Animal Health Australia – AUSTVETPLAN*. <http://www.animalhealthaustralia.com.au/programs/emergency-animal-disease-preparedness/ausvetplan/disease-strategies/>.

AHA (2013) Disease strategies. *Animal Health Australia – AUSTVETPLAN*. <http://www.animalhealthaustralia.com.au/programs/emergency-animal-disease-preparedness/ausvetplan/disease-strategies/>.

Anderson N, Waller PJ (1983) *The Epidemiology and Control of Gastrointestinal Parasites of Cattle in Australia*. CSIRO Publishing, Melbourne.

APVMA (2012) *Australia Pesticides and Veterinary Medicines Authority: Public Chemical Registration Information System*. <http://services.apvma.gov.au/PubcrisWebClient/welcome.do>.

AVJ (2002) Tickgard Plus relaunched to fight cattle ticks. *Australian Veterinary Journal* **80**, 394. doi:10.1111/j.1751-0813.2002.tb10990.x.

Ballweber LR (2006) Endoparasite control. *Veterinary Clinics of North America. Food Animal Practice* **22**, 451–461. doi:10.1016/j.cvfa.2006.03.002.

Barrington GM, Gay JM, Evermann JF (2002) Biosecurity for neonatal gastrointestinal diseases. *Veterinary Clinics of North America. Food Animal Practice* **18**, 7–34. doi:10.1016/S0749-0720(02)00005-1.

Bazeley K (2003) Investigation of diarrhoea in the neonatal calf. *In Practice* **25**, 152–159. doi:10.1136/inpract.25.3.152.

Beam AL, Lombard JE, Kopral CA, Garber LP, Winter AL, Hicks JA, Schlater JL (2009) Prevalence of failure of passive transfer of immunity in newborn heifer calves and associated management practices on US dairy operations *Journal of Dairy Science* **92**, 3973–3980.

Bellows RA, Patterson DJ, Burfening PJ, Phelps DA (1987) Occurrence of neonatal and postnatal mortality in range beef cattle. II. Factors contributing to calf death. *Theriogenology* **28**, 573–586. doi:10.1016/0093-691X(87)90274-3.

Besser TE, Gay CG (1994) The importance of colostrum to the health of the neonatal calf. *Veterinary Clinics of North America. Food Animal Practice* **10**, 107–118.

Blowey RW, Weaver DA (2003) *Color Atlas of Diseases and Disorders of Cattle*. Elsevier, London.

Bock RE, Kingston TG, Standfast NF, de Vos AJ (1999) Effect of cattle breed on innate resistance to inoculations of *Babesia bigemina*. *Australian Veterinary Journal* **77**, 465–466. doi:10.1111/j.1751-0813.1999.tb12094.x.

Bock R, Jackson L, De Vos A, Jorgenson W (2004) Babesiosis of cattle. *Parasitology* **129**, S247–S269. doi:10.1017/S0031182004005190.

Bourke CA (2000) Recent outbreaks of ergot of rye poisoning in sheep and cattle have further clarified the historical confusion that surrounds this problem. *Asian-Australasian Journal of Animal Sciences* **13**, 214.

Bourke CA (2007) A review of kikuyu grass (*Pennisetum clandestinum*) poisoning in cattle. *Australian Veterinary Journal* **85**, 261–267. doi:10.1111/j.1751-0813.2007.00168.x.

Brock KV (2004a) Bovine viral diarrhea virus: persistence is the key. *Veterinary Clinics of North America. Food Animal Practice* **20**, xi–xii.

Brock KV (2004b) The many faces of bovine viral diarrhea virus. *Veterinary Clinics of North America. Food Animal Practice* **20**, 1–3. doi:10.1016/j.cvfa.2003.12.002.

Brooks HW, White DG, Wagstaff AJ, Michell AR (1996) Evaluation of a nutritive oral rehydration solution for the treatment of calf diarrhoea. *British Veterinary Journal* **152**, 699–708. doi:10.1016/S0007-1935(96)80123-0.

Burrin DG, Britton RA (1986) Response to monensin in cattle during subacute acidosis. *Journal of Animal Science* **63**, 888–893.

Campbell JR (2004) Effect of bovine viral diarrhea virus in the feedlot. *Veterinary Clinics of North America. Food Animal Practice* **20**, 39–50. doi:10.1016/j.cvfa.2003.11.003.

Cannon Z (2004) Comparison of oral electrolyte solutions available in Australia for the treatment of neonatal diarrhoea in calves. *Australian Cattle Veterinarian* **30**, 8–19.

Chase CCL, Elmowalid G, Yousif AAA (2004) The immune response to bovine viral diarrhea virus: a constantly changing picture. *Veterinary Clinics of North America. Food Animal Practice* **20**, 95–114. doi:10.1016/j.cvfa.2003.11.004.

Cheeke PR (1995) Endogenous toxins and mycotoxins in forage grasses and their effects on livestock. *Journal of Animal Science* **73**, 909–918.

Colazo MG, Martínez MF, Kastelic JP, Mapletoft RJ, Carruthers TD (2002) The ischiorectal fossa: an alternative route for the administration of prostaglandin in cattle. *Canadian Veterinary Journal. La Revue Veterinaire Canadienne* **43**, 535–541.

Constable PD (2004) Antimicrobial use in the treatment of calf diarrhoea. *Journal of Veterinary Internal Medicine* **18**, 8–17. doi:10.1111/j.1939-1676.2004.tb00129.x.

Cooper VL, Brodersen BW (2010) Preface: bovine respiratory disease. *Veterinary Clinics of North America. Food Animal Practice* **26**, xiii–xiv. doi:10.1016/j.cvfa.2010.04.011.

Craig TM (1988) Impact of internal parasites on beef cattle. *Journal of Animal Science* **66**, 1565–1569.

CRC (2012) *Australian Poll Gene Marker Test Fact Sheet*. Cooperative Research Centre for Beef Genetic Technologies. <http://www.beefcrc.com/documents/publications/fact-sheets/FS01-TheAustralianPollGeneMarkerTest.pdf>.

Cusack PMV, McMeniman N, Lean IJ (2003) The medicine and epidemiology of bovine respiratory disease in feedlots. *Australian Veterinary Journal* **81**, 480–487. doi:10.1111/j.1751-0813.2003.tb13367.x.

DAFF (2013) *National Pests and Disease Outbreaks: Disease Watch Hotline*. Department of Agriculture, Fisheries and Forestry. <http://www.outbreak.gov.au/contact.html>.

DAFWA (2002) *Farm Biosecurity*. Farmnote. <http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/fn071_2002.pdf>.

Dargatz DA (2002) Biosecurity of cattle operations. *Veterinary Clinics of North America. Food Animal Practice* **18**, xi–xii. doi:10.1016/S0749-0720(02)00012-9.

DPI (2004) *Cancer Eye in Cattle*. Agfact. NSW Department of Primary Industries. <http://www.dpi.nsw.gov.au/agriculture/livestock/health/specific/cattle/cancer-eye-in-cattle>.

DPI (2011) *Heart-leaf Poison Bush*. Fact Sheet. Biosecurity Queensland. <http://www.dpi.qld.gov.au/documents/Biosecurity_EnvironmentalPests/IPA-Heart-Leaf-Poison-Bush-PP51.pdf>.

Edwards TA (2010) Control methods for bovine respiratory disease for feedlot cattle. *Veterinary Clinics of North America. Food Animal Practice* **26**, 273–284. doi:10.1016/j.cvfa.2010.03.005.

Entwistle K, Fordyce G (2003) *Evaluating and Reporting Bull Fertility*. Australian Association of Cattle Veterinarians, Indooroopilly.

Entwistle KW, Goddard ME (1984) Evaluation of large ruminants for the tropics. In *Evaluation of Large Ruminants for the Tropics*. (Ed. AD Wilson). ACIAR, Canberra.

EUD (2012) *Animal Welfare Education: Five Freedoms*. EU Directorate-General for Health and Consumers. <www.animalwelfare-education.eu/information/five-freedoms.html>.

FAWC (1979) *Press Statement: The Five Freedoms*. Farm Animal Welfare Council. <www.fawc.org.uk/freedoms.htm>.

Ferreira BR, Silva JS (1998) Saliva of *Rhipicephalus sanguineus* tick impairs T cell proliferation and IFN-Î³-induced macrophage microbicidal activity. *Veterinary Immunology and Immunopathology* **64**, 279–293. doi:10.1016/S0165-2427(98)00135-4.

Flynn M (2001) Dung beetles reduce livestock costs. Australian Landcare June, 12–13.

Foil LD, Coleman P, Eisler M, Fragoso-Sanchez H, Garcia-Vazquez Z, Guerrero FD, Jonsson NN, Langstaff IG, Li AY, Machila N, Miller RJ, Morton J, Pruett JH, Torr S (2004) Factors that influence the prevalence of acaricide resistance and tick-borne diseases. *Veterinary Parasitology* **125**, 163–181. doi:10.1016/j.vetpar.2004.05.012.

Francoz D, Buczinski SB, Apley M (2012) Evidence related to the use of ancillary drugs in bovine respiratory disease (anti-inflammatory and others): are they justified or not? *Veterinary Clinics of North America. Food Animal Practice* **28**, 23–38. doi:10.1016/j.cvfa.2011.12.003.

Fraser DM (2008) *Understanding Animal Welfare: The Science in its Cultural Context*. Wiley-Blackwell, Chichester.

Fraser DM, Dorling PR (1983) Suspected ergotism in two heifers. *Australian Veterinary Journal* **60**, 303–305. doi:10.1111/j.1751-0813.1983.tb02814.x.

Galyean ML, Perino LJ, Duff GC (1999) Interaction of cattle health/immunity and nutrition. *Journal of Animal Science* **77**, 1120–1134.

Gee RW, Bainbridge MH, Haslam JY (1971) The effect of cattle tick (*Boophilus microplus*) on beef production in the Northern Territory. *Australian Veterinary Journal* **47**, 257–263. doi:10.1111/j.1751-0813.1971.tb02146.x.

Grandin T (1994) Euthanasia and slaughter of livestock *Journal of the American Veterinary Medical Association* **204**, 1354–1360.

Greenall R, Graham J (2011) *Bloat Prevention in Pasture-fed Beef Cattle*. Department of Primary Industries Victoria. <http://www.dpi.vic.gov.au/agriculture/pests-diseases-and-weeds/animal-diseases/beef-and-dairy-cows/bloat-prevention-in-pasture-fed-beef-cattle>.

Grooms DL (2004) Reproductive consequences of infection with bovine viral diarrhea virus. *Veterinary Clinics of North America. Food Animal Practice* **20**, 5–19. doi:10.1016/j.cvfa.2003.11.006.

Guerin L (2013) *Don't Fence Me In: The Virtual Alternative*. Bestprac. <http://www.bestprac.info/pages/posts/donrsquot-fence-me-in–the-virtual-alternative_-425.php>.

Gwynn R, Gabbedy BJ, Hopkinson WI, Kay BE, Wood PM (1974) Kikuyu poisoning of cattle in Western Australia. *Australian Veterinary Journal* **50**, 369–370. doi:10.1111/j.1751-0813.1974.tb14116.x.

Holroyd RG (1987) Foetal and calf wastage in *Bos indicus* cross beef genotypes. *Australian Veterinary Journal* **64**, 133–137. doi:10.1111/j.1751-0813.1987.tb09661.x.

Houpt K (2011) *Domestic Animal Behaviour for Veterinarians and Animal Scientists*. Wiley-Blackwell, Ames, Iowa.

Islam MK, Jabbar A, Campbell BE, Cantacessi C, Gasser RB (2011) Bovine theileriosis: an emerging problem in south-eastern Australia? *Infection, Genetics and Evolution* **11**, 2095–2097. doi:10.1016/j.meegid.2011.08.012.

Izzo MM, Poe I, Horadagoda N, De Vos AJ, House JK (2010) Haemolytic anaemia in cattle in NSW associated with

Theileria infections. *Australian Veterinary Journal* **88**, 45–51. doi:10.1111/j.1751-0813.2009.00540.x.

Johnston LAY, Sinclair DF (1980) Differences in response to experimental primary infection with *Babesia bovis* in Hereford, Droughtmaster and Brahman cattle. In *Ticks and Tick-borne Diseases. Proceedings of the 56th Annual Conference of the Australian Veterinary Association*. (Eds LAY Johnston and MG Cooper).

Jonsson NN (2006) The productivity effects of cattle tick (*Boophilus microplus*) infestation on cattle, with particular reference to *Bos indicus* cattle and their crosses. *Veterinary Parasitology* **137**, 1–10. doi:10.1016/j.vetpar.2006.01.010.

Jonsson NN, Bock RE, Jorgensen WK (2008) Productivity and health effects of anaplasmosis and babesiosis on *Bos indicus* cattle and their crosses, and the effects of differing intensity of tick control in Australia. *Veterinary Parasitology* **155**, 1–9. doi:10.1016/j.vetpar.2008.03.022.

Jubb T (2008) Biosecurity risk management planning for livestock enterprises. A training course for animal health advisors – resource manual. Livestock Health Systems Australia.

Kamau J, De Vos AJ, Playford M, Salim B, Kinyanjui P, Sugimoto C (2011) Emergence of new types of *Theileria orientalis* in Australian cattle and possible cause of *Theileriosis* outbreaks. *Parasites and Vectors* **4**, 22.

Kaplan RM, Vidyashankar AN (2012) An inconvenient truth: global worming and anthelmintic resistance. *Veterinary Parasitology* **186**, 70–78. doi:10.1016/j.vetpar.2011.11.048.

Kelling CL (2004) Evolution of bovine viral diarrhea virus vaccines. *Veterinary Clinics of North America. Food Animal Practice* **20**, 115–129. doi:10.1016/j.cvfa.2003.11.001.

Kessell AE (2010) *Annual Ryegrass Toxicity: Current Situation*. Farmnote. Department of Agriculture and Food Western Australia. <http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/ah/dis/fn_argt_tox.pdf>.

Kirkland PD (2002) Akabane and bovine ephemeral fever virus infections. *Veterinary Clinics of North America. Food Animal Practice* **18**, 501–514. doi:10.1016/S0749-0720(02)00026-9.

Kleen JL, Hooijer GA, Rehage J, Noordhuizen JPTM (2003) Subacute ruminal acidosis (SARA): a review. *Journal of Veterinary Medicine Series A* **50**, 406–414. doi:10.1046/j.1439-0442.2003.00569.x.

Larson RL (2008) Epidemiology and disease control in everyday beef practice. *Theriogenology* **70**, 565–568. doi:10.1016/j.theriogenology.2008.04.011.

Larson RL, Step DL (2012) Evidence-based effectiveness of vaccination against *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni* in feedlot cattle for mitigating the incidence and effect of bovine respiratory disease complex. *Veterinary Clinics of North America. Food Animal Practice* **28**, 97–106. doi:10.1016/j.cvfa.2011.12.005.

Larson RL, Tyler JW (2005) Reducing calf losses in beef herds. *Veterinary Clinics of North America. Food Animal Practice* **21**, 569–584. doi:10.1016/j.cvfa.2005.02.009.

Lehane R (1991) Biological control of Paterson's curse: prospects look good. *Rural Research* 151, 8–12.

Littler B, House JK (2001) *Dark Cutting Beef : The Economic Loss*. Agnote. NSW Government. <http://www.dpi.nsw.gov.au/agriculture/livestock/beef/market/publications/dcb-economic-loss>.

Lucy MC (2004) New tools for managing reproduction. *Animal Production in Australia* **25**, 363–372.

Maclachlan NJ, Drew CP, Darpel KE, Worwa G (2009) The pathology and pathogenesis of bluetongue. *Journal of Comparative Pathology* **141**, 1–16. doi:10.1016/j.jcpa.2009.04.003.

Mariasegaram M, Harrison BE, Bolton JA, Tier B, Henshall JM, Barendse W, Prayaga KC (2012) Fine-mapping the POLL locus in Brahman cattle yields: the diagnostic marker CSAFG29. *Animal Genetics* **43**, 683–688. doi:10.1111/j.1365-2052.2012.02336.x.

Mathews K (2011) *A Review of Australia's Preparedness for the Threat of Foot-and-mouth Disease*. Department of Agriculture, Fisheries and Forestry, Canberra.

McKay AC, Ophel KM, Reardon TB, Gooden JM (1993) Livestock deaths associated with *Clavibacter toxicus/Anguina* sp. infection in seedheads of *Agrostis avenacea* and *Polypogon monspeliensis*. *Plant Disease* **77**, 635–641. doi:10.1094/PD-77-0635.

McKenzie RA (2012) *Australia's Poisonous Plants, Fungi and Cyanobacteria*. CSIRO Publishing, Melbourne.

McLeod RS (1995) Costs of major parasites to the Australian livestock industries. *International Journal for Parasitology* **25**, 1363–1367. doi:10.1016/0020-7519(95)00071-9.

Melville L, Pinch D (2003) *Bluetongue in cattle*. Agnote. Northern Territory Department of Primary Industries.

Mickelsen WD, Evermann JF (1994) In utero infections responsible for abortion, stilbirth and birth of weak calves in beef cows. *Veterinary Clinics of North America. Food Animal Practice* **10**, 1.

MIMS (2011) *MIMS Australia – IVS Annual*. UBM Medica Australia Pty Ltd.

MLA (2003) *Recommendations for Integrated Buffalo Fly Control*. Meat and Livestock Australia, Sydney.

MLA (2005a) *Cattle Parasite Atlas*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/CustomControls/PaymentGateway/ViewFile.aspx?CBSGoUKScHlFpDxts9F1BXR1zhSqeOSm5uhX8cawsZb4Hq10A8j9tgBF83sXk9OF3EYMKKAfsht7d1Tnt3BqiA==>.

MLA (2005b) *Neonatal Calf Diarrhoea in Suckler Beef Herds*. Meat and Livestock Australia, Sydney.

MLA (2010) *Tips and Tools: Controlling Bovine Respiratory Disease in Feedlot Cattle*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/CustomControls/PaymentGateway/ViewFile.aspx?XvzJRdYFXczt4dBmNCyxTOT2rCVrUEqMjMePv68pCEBh9W/+Wk7dNOEuKBvyDD3j3EYMKKAfsht7d1Tnt3BqiA==>.

MLA (2011a) *Cattle Parasite Atlas*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Livestock-production/Animal-health-welfare-and-biosecurity/Parasites/Cattle-parasite-atlas>.

MLA (2011b) *Ticks*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Livestock-production/Animal-health-welfare-and-biosecurity/Parasites/Identification/Ticks>.

MLA (2012a) *Animal Handling*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/livestock-production/

animal-health-welfare-and-biosecurity/husbandry/animal-handling>.

MLA (2012b) *Parasites*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Livestock-production/Animal-health-welfare-and-biosecurity/Parasites>.

MLA (2012c) *Paterson's Curse*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Livestock-production/Animal-health-welfare-and-biosecurity/Poisonings/Toxic-plants/Patersons-curse>.

MLA (2013) *Animal Handling*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/livestock-production/animal-health-welfare-and-biosecurity/husbandry/animal-handling>.

Nagaraja TG, Lechtenberg KF (2007a) Acidosis in feedlot cattle. *Veterinary Clinics of North America. Food Animal Practice* **23**, 333–350. doi:10.1016/j.cvfa.2007.04.002.

Nagaraja TG, Lechtenberg KF (2007b) Liver abscesses in feedlot cattle. *Veterinary Clinics of North America. Food Animal Practice* **23**, 351–369. doi:10.1016/j.cvfa.2007.05.002.

Nagaraja TG, Titgemeyer EC (2007) Ruminal acidosis in beef cattle: the current microbiological and nutritional outlook. *Journal of Dairy Science* **90**(Supplement), E17–E38. doi:10.3168/jds.2006-478.

NAMP (2012) *Bluetongue Virus Zones in Australia*. National Arbovirus Monitoring Program. Animal Health Australia. <http://namp.animalhealthaustralia.com.au/public.php?page=namp_public&program=2>.

Nickell JS, White BJ (2010) Metaphylactic antimicrobial therapy for bovine respiratory disease in stocker and feedlot cattle. *Veterinary Clinics of North America. Food Animal Practice* **26**, 285–301. doi:10.1016/j.cvfa.2010.04.006.

O'Connor AM, Brace S, Gould S, Dewell R, Engelken T (2011) A randomized clinical trial evaluating a farm-of-origin autogenous *Moraxella bovis* vaccine to control infectious bovine keratoconjunctivis (pinkeye) in beef cattle. *Journal of Veterinary Internal Medicine* **25**, 1447–1453. doi:10.1111/j.1939-1676.2011.00803.x.

Oswin S (2012) *What does BRD cost the feedlot?* - Vet column, *Beef Central*. <http://www.beefcentral.com/feedlot/article/1326>.

Parkinson TJ, Vermunt JJ, Malmo J (2010) *Diseases of Cattle in Australasia*. VetLearn, Wellington.

Peet RL, McCarthy MR, Barbetti MJ (1991) Hyperthermia and death in feedlot cattle associated with the ingestion of *Claviceps purpurea*. *Australian Veterinary Journal* **68**, 121 doi:10.1111/j.1751-0813.1991.tb00777.x.

Pegg GG, Oberoi G, Aspden WJ, D'Occhio MJ (1994) Pimelea poisoning of cattle. In *Vaccines in Agriculture: Immunological Applications to Animal Health and Production: Workshop*, pp. 155-159. CSIRO Publishing, Melbourne.

Peterson JE (1985) The toxicity of *Echium plantagineum* (Paterson's curse). In *Plant Toxicology. Proceedings of the Australia–U.S.A. Poisonous Plants Symposium*, Brisbane, 14–18 May 1984, pp. 191–199.

Phillips C (1993) *Cattle Behaviour.* Diamond Farm Book Publications.

Phillips C (2002) *Cattle Behaviour and Welfare*. Blackwell Science, Oxford.

Poulsen KP, McGuirk SM (2009) Respiratory disease of the bovine neonate. *Veterinary Clinics of North America. Food Animal Practice* **25**, 121–137. doi:10.1016/j.cvfa.2008.10.007.

Prayaga KC (2007) Genetic options to replace dehorning in beef cattle: a review. *Australian Journal of Agricultural Research* **58**, 1–8. doi:10.1071/AR06044.

Reed K (2007) *Tips and Tools: Perennial Ryegrass Toxicosis*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/CustomControls/PaymentGateway/ViewFile.aspx?5MCGYEPsiGKsj2hKwEKocvPGqOEeL1L2IL0m8ZN+LxW/DynL5DdUZQnp7TqhbHrM3EYMKKAfsht7d1Tnt3B-qiA==>.

Reed KFM, Moore DD (2009) A preliminary survey of zearalenone and other mycotoxins in Australian silage and pasture. *Animal Production Science* **49**, 696–703. doi:10.1071/EA08164.

Rice LE (1994) Dystocia-rlated risk factors. *Veterinary Clinics of North America. Food Animal Practice* **10**, 53–68.

Ridpath J (2010) The contribution of infections with bovine viral diarrhea viruses to bovine respiratory disease. *Veterinary Clinics of North America. Food Animal Practice* **26**, 335–348. doi:10.1016/j.cvfa.2010.04.003.

Rings DM (2004) Clostridial disease associated with neurologic signs: tetanus, botulism, and enterotoxemia. *Veterinary Clinics of North America. Food Animal Practice* **20**, 379–391. doi:10.1016/j.cvfa.2004.02.006.

Rosseaux CG (1994) Congenital defects as a cause of perinatal mortality of beef calves. *Veterinary Clinics of North America. Food Animal Practice* **10**, 35–52.

Rothwell JT, Morgan JAT, James PJ, Brown GW, Guerrero FD, Jorgensen WK (2011) Mechanism of resistance to synthetic pyrethroids in buffalo flies in south-east Queensland. *Australian Veterinary Journal* **89**, 70–72. doi:10.1111/j.1751-0813.2010.00685.x.

Ryley MJ, Bourke CA, Liew ECY, Summerell BA (2007) Is *Fusarium torulosum* the causal agent of kikuyu poisoning in Australia? *Australasian Plant Disease Notes* **2**, 133–135. doi:10.1071/DN07053.

Sackett D, Holmes P, Abbott K, Jephcott S, Barber M (2006) Assessing the economic cost of endemic disease on the profitability of Australian beef cattle and sheep producers Animal Health and Welfare Final Report. Project Code AHW.087. Meat and Livestock Australia, Sydney.

Singer P (1976) *Animal Liberation*. Cape, London.

Slatter DH, Edwards ME, Hawkins CD, Wilcox GE (1982) A national survey of the clinical features, treatment and importance of infectious bovine keratoconjunctivitis. *Australian Veterinary Journal* **59**, 69–72. doi:10.1111/j.1751-0813.1982.tb02729.x.

Smith GW (2009) Treatment of calf diarrhoea: oral fluid therapy. *Veterinary Clinics of North America. Food Animal Practice* **25**, 55–72. doi:10.1016/j.cvfa.2008.10.006.

Smith DR, Grotelueschen DM (2004) Biosecurity and biocontainment of bovine viral diarrhea virus. *Veterinary Clinics of North America. Food Animal Practice* **20**, 131–149. doi:10.1016/j.cvfa.2003.11.008.

Spence S (2007) *Buffalo Flies and their Control.* Primefacts. Department of Primary Industries NSW. <http://www.dpi.

nsw.gov.au/__data/assets/pdf_file/0017/110915/buffalo-flies-and-their-control.pdf>.

Spradbrow PB, Wilson BE, Hoffma D (1977) Immunotherapy of bovine ocular squamous cell carcinoma. *Veterinary Record* **100**, 376–378. doi:10.1136/vr.100.18.376.

Stokka GL, Lechtenberg K, Edwards T, MacGregor S, Voss K, Griffin D, Grotelueschen DM, Smith RA, Perino LJ (2001) Lameness in feedlot cattle. *Veterinary Clinics of North America. Food Animal Practice* **17**, 189–207.

Sullivan RM, O'Rourke PK (1997) A comparison of once- and twice-yearly weaning of an extensive herd in northern Australia. *Australian Journal of Experimental Agriculture* **37**, 279–286. doi:10.1071/EA95097.

Sutherland IA, Leathwick DM (2011) Anthelmintic resistance in nematode parasites of cattle: a global issue? *Trends in Parasitology* **27**, 176–181. doi:10.1016/j.pt.2010.11.008.

Sutherst R, Maywald G, Kerr J, Stegeman D (1983) The effect of cattle tick (*Boophilus microplus*) on the growth of *Bos indicus* and *B. taurus* steers. *Australian Journal of Agricultural Research* **34**, 317–327. doi:10.1071/AR9830317.

Townsend HGG (1994) Environmental factors and calving managment practices that affect neonatal mortality in the beef calf. *Veterinary Clinics of North America. Food Animal Practice* **10**, 119–126.

Tsujita H, Plummer CE (2010) Bovine ocular squamous cell carcinoma. *Veterinary Clinics of North America. Food Animal Practice* **26**, 511–529. doi:10.1016/j.cvfa.2010.08.003.

Turner AJ (2011) Quarantine, exports and animal disease in Australia 1901–2010. *Australian Veterinary Journal* **89**, 366–371.

Uren MF (1989) Bovine ephemeral fever. *Australian Veterinary Journal* **66**, 233–236. doi:10.1111/j.1751-0813.1989.tb13577.x.

Van Wyk JA (2006) Face facts: drenching with anthelmintics for worm control selects for drug resistance and no excuses! *Proceedings of the New Zealand Society of Animal Production* **66**, 4–13.

Vermunt JJ (1994) Rearing and management of diarrhoea in calves to weaning. *Australian Veterinary Journal* **71**, 33–41. doi:10.1111/j.1751-0813.1994.tb06149.x.

Vogels Z (2010) Calf fluid therapy made simple. *Australian Cattle Veterinarians Annual Conference*. Australian Veterinary Association.

Walker PJ (2005) Bovine ephemeral fever in Australia and the world. In *The World of Rhabdoviruses* (Ed. Z Fu, Z) pp. 57–80. Springer, Berlin.

Waller PJ (1997) Anthelmintic resistance. *Veterinary Parasitology 72,* 391–412.

Watt G (2006) *Eye Cancer in Cattle*. Department of Primary Industries Victoria. <http://www.dpi.vic.gov.au/agriculture/pests-diseases-and-weeds/animal-diseases/beef-and-dairy-cows/eye-cancer-in-cattle>.

Weaver DM, Tyler JW, VanMetre DC, Hostetler DE, Barrington GM (2000) Passive transfer of colostral immunoglobulins in calves. *Journal of Veterinary Internal Medicine* **14**, 569–577. doi:10.1111/j.1939-1676.2000.tb02278.x.

Webster J (Ed.) (2011) *Management and Welfare of Farm Animals*. Wiley-Blackwell, Chichester.

White N, Sutherst RW, Hall N, Whish-Wilson P (2003) The vulnerability of the Australian beef industry to impacts of the cattle tick (*Boophilus microplus*) under climate change. *Climatic Change* **61**, 157–190. doi:10.1023/A:1026354712890.

Wikse SE, Kinsel ML, Field RW, Holland PS (1994) Investigating perinatal calf mortality in beef herds. *Veterinary Clinics of North America. Food Animal Practice* **10**, 147–166.

Williams DL (2010) Welfare issues in farm animal ophthalmology. *Veterinary Clinics of North America. Food Animal Practice* **26**, 427–435. doi:10.1016/j.cvfa.2010.08.005.

Williams JD, Sutherst RW, Maywald GF, Petherbridge CT (1985) The southward spread of buffalo fly (*Haematobia irritans exigua*) in eastern Australia and its survival through a severe winter. *Australian Veterinary Journal* **62**, 367–369. doi:10.1111/j.1751-0813.1985.tb14210.x.

Wilson LK, Tyler JW, Besser TE, Parish SM, Gant R (1999) Prediction of serum IgG1 concentration in beef calves based on age and serum gamma-glutamyl-transferase activity. *Journal of Veterinary Internal Medicine* **13**, 123–125.

Zielinski GC, Piscitelli HG, Perez-Monti H, Stobbs LA, Zimmermann AG (2002) Efficacy of different dosage levels and administration routes of tilmicosin in a natural outbreak of infectious bovine keratoconjunctivitis (pinkeye). *Veterinary Therapeutics* **3**, 196–205.

14 Reproductive management of beef cattle

R.G. Holroyd and M.R. McGowan

INTRODUCTION

Sound reproductive management of beef cattle, based on good scientifically tested principles, is critical to optimising reproductive performance. Reproductive management covers a host of issues not only from conception to weaning a calf but also rearing replacements and managing cull cows and bulls until sold or slaughtered. Our definition of reproductive management is the application of various techniques such as husbandry procedures, nutritional manipulation, disease control and genetic selection (Chapter 17) to optimise reproductive performance.

It is important to distinguish between maximising and optimising reproductive performance. Maximising is increasing or enhancing, to the highest level, traits such as the number of progeny produced, weight of females at mating or scrotal circumference of bulls. While these are laudable objectives they should not be at the expense of other traits such as the survival of lactating females in the dry season or an increase in dystocia rates of heifers. Optimising is the best compromise between increasing output (per unit input) without jeopardising resource sustainability or compromising animal welfare.

The language of the beef industry is not uniform and has been modified depending on location and other farm enterprises. For instance, mating and joining are the same but 'mating' is the vernacular in northern Australia and 'joining' is used in southern Australia, a rub-off from the sheep industry. Other different names with common meanings are 'branding' and 'marking', and 'scrotal size' and 'scrotal circumference'. Also confusing is the term 'heifer' and when this animal transforms to a 'cow'. The following definitions of females will be used:

- weaner heifers – females from weaning until ~12 months of age;
- maiden heifers or heifers – heifers being joined for the first time. These could be as yearlings (from ~12–15 months onwards) or as two-year-olds;
- first lactation cows – females from their first calving to weaning of that calf;
- mature cows – from weaning of their first calf until 10 years;
- aged cow – older than 10 years.

The principles of reproductive management are similar across the vastly different environmental regions of Australia. There are some marked differences in management across the regions due to different rainfall distribution, soil types and pastures. Management also varies between properties within regions because of different enterprise objectives (Chapter 18). There is no standard set of rules for all properties and all situations, but various techniques or principles that can optimise reproductive performance compatible with the objective of the enterprise are highlighted throughout this chapter.

AUSTRALIA'S BEEF CATTLE PRODUCTION ENVIRONMENTS

Australia's beef breeding herds are run almost entirely on native or improved pastures with negligible cattle housed at any time of the year. These grasslands experience wide climatic variation that markedly affects growth and reproductive rate. Breeding enterprises invariably fall into three types: breeding and fattening progeny for slaughter, breeding and selling young cattle for finishing on other properties, feedlots (Chapter 11) or for live export (Chapter 12), or the seedstock sector where cattle are bred for sale as bulls or breeding females. At least 95% of the national herd is naturally mated. Most assisted breeding technologies are confined to the stud sector aimed at the multiplication of progeny of superior genetics for breeding in commercial herds. Projections of their future use are as high as 10%, with the main areas of adoption being in commercial herds. Until assisted breeding technologies are simpler and more economic in the commercial sector, the proportion of the national herd mated this way will remain low.

Production systems for beef cattle can be classified as intensive or extensive (Entwistle 1984). Intensive systems (Chapter 10), generally in the higher-rainfall areas of temperate, subtropical and tropical Australia, are characterised by:

- breeder herd sizes ranging from 50–2000 head;
- generally high stocking rates ranging from 0.2–2 adult equivalents (AE)/ha (equal to 1.5–16 DSE/ha);
- moderate to good levels of property development;
- reasonable levels of cattle control;
- beef cattle enterprises frequently combined with sheep and agriculture.

Extensive systems (Chapter 9) are generally in the seasonally wet summer-rainfall areas of tropical Australia but also include the western region of NSW and the northern parts of SA. These properties are characterised by:

- breeder herd sizes ranging from 500–20 000 head or more;
- low stocking rates ranging from 0.02–0.2 AE/ha (0.15–1.5 DSE/ha);
- minimal (cattle harvesting) to good levels of property development;
- specialist beef cattle enterprises with little opportunity for diversification.

The influence of climatic conditions on pasture production and quality have a noticeable influence on cattle productivity. Much of this effect is reflected in differences in liveweight and liveweight change, which influences survival, fertility and age at sale. Marked year-to-year differences in annual growth rates have a marked effect on overall herd fertility. For instance, Rudder *et al.* (1985) in central Queensland recorded significant year effects on reproductive rates, such effects having a larger and more consistent influence than either breed or cow age. The marked year variations in reproductive performance mainly reflect differences in nutritional stress during the previous dry season (Entwistle and Goddard 1984).

INDICES FOR MEASURING BEEF CATTLE REPRODUCTION

Common indices include pregnancy rates, calving rates, branding rates and weaning rates, all expressed as a percentage of females mated to bulls the previous year (McGowan and Holroyd 2008). All of these have inadequacies in accurately defining reproductive performance in a way that not only allows an unbiased comparison between properties and management systems, but as a method of accurately pinpointing inefficiencies in the reproductive chain of events. Pregnancy rates are useful with short mating periods as they give a good indication of the number of animals that conceive in a particular mating period. With year-round mating systems, pregnancy rates report only the numbers pregnant at a particular observation. Pregnancy rates do not account for subsequent pre-natal, peri-natal and post-natal losses. Calving, branding and weaning rates are, respectively, the number of calves born (both alive and dead), branded (at time of branding and castration) or weaned as the proportion of the number of cows mated the previous year. Calving rates are difficult to determine in extensive herds because of property size and often adverse seasonal conditions in which to muster or to observe cattle. Branding rate is the common index of fertility in extensive herds but suffers from inaccuracy in that, although calf numbers are recorded, cow numbers since mating are usually estimated because of mortalities, sales or animals missed at musters. Weaning rate is the best index of fertility as it represents the breeding output from the herd as well as the period upon which the calf is dependent on the cow for its survival. Weaning rate suffers from the same inadequacies, however, as the calculation of calving and branding rates. In many situations branding rate and weaning rate are similar, as branding coincides with weaning.

Reproductive performance is best measured by annual breeder beef production efficiency. This is a combination of weight of cows, both retained and culled, and weight of calves weaned (McGowan *et al.* 2013). The three key traits influencing breeder beef production are the percentage of females which are pregnant within four months of calving, the level of foetal and calf wastage and the number and weight of weaners. This approach requires more detailed record-keeping but measurement is the key to business analysis and improvement (McGowan *et al.* 2013; Chapter 18).

Reproductive targets

The gold standard for reproductive efficiency is a calf weaned for every cow mated per year. However, this is biologically impossible, particularly in extensive rangeland systems where there are marked variations in seasonal pasture growth resulting in marked loss in body condition, particularly in lactating cows in drought years. This target may not be desirable when the sale of non-pregnant cows in good body condition represents a significant component of income (Wicksteed 1980).

From reviews of fertility data over the last 30 years, a realistic target for weaning rates for tropically adapted cattle in northern Australia is 80 calves weaned for each 100 cows mated (McGowan and Holroyd 2008). This requires a 90% pregnancy rate across all classes of breeders and allows for a 10% unit loss from confirmed pregnancy to weaning. Based on ABARE data, the target weaning rates for southern Australia should be 90% (Wilkins 2006). This allows for a 95% pregnancy rate and a 5% unit loss from pregnancy to weaning. To achieve these levels of weaning rates consistently, given climatic variation, is extremely difficult.

Reproductive rates for Australian beef herds

There have been numerous estimates of regional, state or national reproductive rates. They have been derived from ABARE returns (Wilkins 2006), producer surveys (O'Rourke *et al.* 1992), published scientific reports (Holroyd and O'Rourke 1989; Hasker 2000) and detailed on-property data collection (Bortolussi *et al.* 2005; McCosker *et al.* 2011b). Most extensive properties fall well short of the 80–85% target weaning rates. O'Rourke *et al.* (1992) reported that branding rates in northern beef herds averaged 63%, ranging from 48% in the Gulf of Carpentaria region to 73% in inland central and southern Queensland. The collation of data from 1990 to 2010 (McCosker *et al.* 2011b) suggested little improvement in herd reproductive performance compared with that of O'Rourke *et al.* (1992). Median pregnancy rates averaged 76% with a 14% loss from pregnancy to weaning. Wilkins' data (2006) for southern Australia suggest that average branding rates are approaching the 85% target. Further efficiencies of production could be made through shortening the calving period.

Documenting reproductive performance as kilograms of weaner/cow/year may provide a more meaningful estimate of efficiency. Median or achievable levels for better country such as the Mitchell grass downs are 150 kg/cow/year, and 90 kg/cow/year for forest country in northern Australia (McGowan *et al.* 2013).

Economics of improving reproductive performance

The economics of lifting reproductive performance has been based on marketing trends at the time of analysis. Wicksteed (1980) considered that in central Queensland there was an economic ceiling to improving weaning rates above 70%, in that improvements beyond this level had little impact on property profitability. These calculations were based on selling steers up to 4.5 years of age. Since then, there has been a marked reduction in the age of turnoff of cattle through the proliferation of feedlots and the live export trade (Chapters 12, 16). Data by Best (2007) from central Queensland indicated that lifting weaning rates from 65% to 75% increased gross margins (GM) per adult equivalent from \$118 to \$140 in store steer systems and from \$150 to \$170 in two-year-old steer fattening systems. Further work by Holmes (2010) examined the effects of improving reproductive rates in four typical beef production systems in Queensland. Improved reproductive performance led to a higher GM in each system. Considered in the context of modern beef production markets, there is a good argument to increase weaning rates to meet reproductive targets.

PRINCIPLES OF IMPROVING REPRODUCTIVE EFFICIENCY

An analysis of the southern Australian beef industry (Holmes Sackett 2010) showed significant potential to increase herd productivity principally by optimising stocking rate, ensuring optimum age and weight at sale and optimising herd weaning weight through cost-effective management of nutrition, breeding and weaning. However, it also cautioned that productivity improvements should consider the cost of change; in many cases lower costs and/or simpler options are best undertaken before implementation of more expensive alternatives.

This philosophy (Holmes Sackett 2010) supports that of Fordyce and Holroyd (2003). The latter authors described a hierarchy of management options that can be implemented to improve reproductive efficiency in northern Australia. Basic issues such as sustaining the pasture resource and effective cattle control are prerequisites to the effective application of management techniques. Effective cattle control will allow segregation of different classes of cattle, keeping them where required and allowing mustering at minimum cost and effort. It also allows for more effective implementation of other management practices. Important segregation groups are small weaners, older weaners, heifers, first lactation cows, mature cows, cull females, bulls when not breeding, immature bulls and steers.

Management options can be classified as four stages (Fordyce and Holroyd 2003):

- first level – appropriate genotype, supplementation, weaning and weaning management and control of major infectious causes of mortality, e.g. botulism;
- second-level – heifer management, selection of replacement females, efficient culling, venereal disease control and bull soundness;
- third level – seasonal mating, spike feeding, dry-season segregation of cows and artificial insemination;
- fourth level – high-input supplementation and feeding systems, embryo transfer and twinning.

Through all levels of management, implementation should be in stages to ensure that the resources and skills to implement any option are in place before the next stage is attempted, and that the financial benefit from each stage can finance the next (Fordyce and Holroyd 2003).

Effect of liveweight and body condition on fertility of females

Each heifer or cow, depending on breed, age, lactation status and time of year, has a high probability of conception within certain liveweight and body condition ranges. Liveweight and body condition score (BCS) are interrelated. Liveweight tends to be a measure more commonly reported for heifers and non-lactating cows while BCS is used more frequently with lactating cows. This is partly because assessing BCS in the paddock is easier; recording liveweight requires mustering as well as potential problems with mismothering of calves.

Liveweight

The target weight concept introduced by Lamond (1970) is the weight at which puberty or pregnancy can occur. Part of the confusion in comparing data is that the 'target' reflects different stages of the reproductive management cycle. The most commonly used target is weight at start of mating, hence the terminology 'critical mating weight' (CMW). For southern beef herds, CMW is defined as the weight at the start of mating at which 85% or more of heifers will get pregnant (diagnosed six to eight weeks after bull removal) in a 45-day mating period (Manning 2004). For northern beef herds, it is the weight at start of mating to ensure that most heifers get pregnant early in the mating period (Schatz 2012).

The relationship between liveweight at start of mating and pregnancy rate tends to be curvilinear for heifers and mature cows and linear in first lactation cows (Fig. 14.1). These data were derived from several sources for *Bos indicus* and *Bos indicus* cross cattle in north Queensland where heifers, first calf cows and mature cows were respectively two, three and four or more years of age at start of mating. The trends apply equally to *Bos taurus* breeds in southern Australia except that the age of animals would be 12 months less for each class.

Dixon (1998), in summarising data from several northern Australian herds, concluded that for lactating cows <340 kg at mating, a 5% unit increase in pregnancy rate could be expected for each additional 10 kg liveweight achieved by improved nutrition leading up to the time of mating. For cows >340 kg at mating, the response is more likely to be a 3% unit increase, with younger cows more likely to be sensitive to these responses.

Figure 14.1 does not give an indication of how quickly animals conceive after the start of mating or an indication of the rebreeding rate at the next mating, hence the introduction of 'target mating weight' (TMW) (Fordyce 2006). TMW is the average weight of a cohort at the start of mating during which 90% of heifers are expected to conceive. The length of mating has a critical effect on TMW – the aim is for heifers to have their third ovulation before the end of mating so that subsequent calving dates

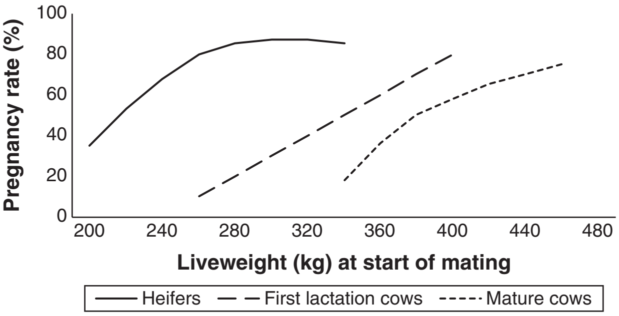


Figure 14.1: Liveweight at start of mating and subsequent pregnancy rates in *Bos indicus* cross females in north Queensland. Source: Adapted from Goddard *et al.* (1980); Anderson (1990); Doogan *et al.* (1991).

are concentrated (Fordyce 2006). TMW can be calculated by knowing weight at puberty, length of mating period and estimated gain over the mating period, using the equation developed by Fordyce (2006):

$$\text{TMW} = \text{Av. weight at puberty} \times 1.2 + \text{ADG over mating} \times (42 - \text{days of mating})$$

For Brahman heifers with mean weight at puberty of 334 kg (Johnston *et al.* 2009), TMW for a 90-day mating, where projected gains are 1 kg/day over mating, is 353 kg. With a shorter mating period (42 days) but a similar rate of gain, TMW increases to 401 kg. The terms CMW and TMW are used interchangeably but are really quite different. TMW is a more appropriate description rather than CMW as 'critical' implies that if an animal reaches a particular weight it will conceive, which is not always the case.

TMW is difficult to measure in lactating cows with young calves at foot. Also, there is little opportunity to make managerial adjustments at mating if TMW is not going to be reached. An alternative approach is to look at liveweight earlier than start of mating, which is then predictive of subsequent conception rate (Schatz 2011). The pre-mating liveweight of Brahman females in the Northern Territory was recorded about three, six and 14 weeks before mating for yearling heifers, two-year-old heifers and three-year-old first lactation cows, and compared to subsequent pregnancy rates (Fig. 14.2).

Body condition score

BCS describes differences in body composition of both fat and muscle. It is an important determinant of fertility, particularly in lactating females (Entwistle 1984), and is discussed in Chapter 10. Unless otherwise stated, BCS is on a scale of 1 to 5 where 1 is very poor and 5 is overfat. The advantage of BCS is that it can be visually assessed and may account for differences in maturity patterns that may not be reflected in liveweight.

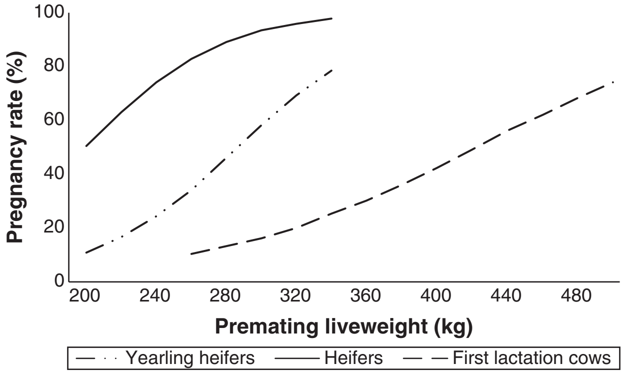


Figure 14.2: Pre-mating liveweight (three, six and 14 weeks respectively before mating) and subsequent pregnancy rates for Brahman yearling heifers, two-year-old heifers and three-year-old first lactation cows in the Northern Territory. Source: Adapted from Schatz (2011).

BCS is a reasonable indicator of liveweight in that Fordyce *et al.* (2013) found that liveweight increased by ~13% for each increase in BCS. Before calving, a change in BCS is equivalent to 53 kg of liveweight in *Bos taurus* cows (Wright *et al.* 1987) and 59 kg in *Bos indicus* heifers (Schatz *et al.* 2011a). The relationships between pre-calving BCS and subsequent fertility of females are addressed below, in the section on factors affecting resumption of cyclicity post-partum.

In summarising the effect of liveweight and body condition on female fertility, the general concept is that the heavier the animal and the better the BCS at the start of mating the greater is the probability that it will conceive, although there may be fertility declines in overfat animals.

PUBERTY IN HEIFERS

Puberty is a sequence of physiological events culminating in the probability of reproductive competence. The onset of puberty depends upon the ability of specific hypothalamic neurons in the brain to produce gonadotrophin-releasing hormone (GnRH) in sufficient quantities to promote and support the development of ovum or spermatozoa. In the female, hypothalamic GnRH neurones must develop the ability to respond to oestradiol feedback before they can produce sufficient quantities of GnRH to cause ovulation (Senger 2003).

Although puberty should be considered as a process rather than a single event, the attainment of puberty is generally regarded as a point in time. There are several methods used to determine whether animals have reached puberty, including recording first behavioural oestrus and first ovulation. Age at first oestrus is relatively easy to determine because females display behavioural signs of sexual receptivity. However, the age of first behavioural oestrus may not be accompanied by ovulation. Age at first ovulation requires regular manual or ultrasonographic examination of the reproductive tract and ovaries to detect the presence of a corpus luteum (CL). Although age at first ovulation is a precise criterion to measure puberty, it lacks practicality in that it requires frequent measurements (Johnston *et al.* 2009). Ultimately heifers have reached puberty when they are capable of conceiving and maintaining a pregnancy. In northern beef herds the majority of heifers reach puberty such that they calve first at three years rather than at two years of age, as happens in many southern Australian beef herds.

Factors affecting age at puberty in heifers

Attainment of puberty is influenced by a threshold body size, exposure to environmental cues and the genetics of the animal (Senger 2003). Within breeds there are huge ranges in age and liveweight at puberty (Table 14.1); detailed reviews of factors affecting puberty appear in Moran *et al*. (1989), Kinder *et al*. (1994) and Schatz (2011). Many of these factors are interrelated and nutritional conditions and growth pathways have a profound influence on liveweight, body condition and fatness. The main factors influencing puberty are given below:

- liveweight and BCS are the major factors, with heifers heavier and in better BCS reaching puberty at a younger age. Low growth rates caused by seasonal undernutriton can substantially increase age at puberty;
- 10–11 months is the age threshold in *Bos indicus* heifers below which puberty will not occur despite high growth rates (Schatz 2011);
- fatness as measured by ultrasound seems to be breed-specific in influencing age at puberty as there is a negative genetic correlation with P8 fat depth in Brahmans but a positive one in tropical composites (Johnston *et al*. 2009);
- genetic factors include breed, sire and dam effects within breeds and heterosis from crossbreeding (Cundiff *et al*. 1986; Chapter 17). Puberty tends to be youngest in *Bos taurus* breeds, intermediate in *Bos indicus x Bos taurus* breeds and oldest in *Bos indicus* breeds;
- month of birth affects age at puberty, with heifers born later in the calving season being older at puberty;
- daylength may be more important than previously considered as influencing onset of puberty. Schillo *et al*. (1992) concluded that pre-pubertal development occurs at a younger age during increased daylength, with the effect more pronounced in Brahmans.

It has been assumed that heifers that reach puberty at a younger age and/or at a lighter weight will have higher lifetime productivity because of a higher probability of conceiving early at first mating. However, these animals, particularly in extensive situations, may be more prone to mortality in the dry season and to prolonged post-partum anoestrus when lactating. Recent data from both Brahman and composite herds concluded that selecting heifers that reach puberty at a young age or lighter weight will not adversely affect beef production efficiency of the cow herd, although this may bias selection towards females with lower mature weight and lighter calves (G Fordyce, pers. comm.).

Table 14.1: Estimates of mean age and liveweight at puberty in some cattle breeds

Breed	Age ± s.d. (months)	Liveweight ± s.d. (kg)
Hereford[1]	12.3 ± 0.3	273 ± 7
Angus[1]	12.4 ± 0.2	276 ± 6
Charolais[1]	12.3 ± 0.3	322 ± 6
Simmental[1]	12.1 ± 0.2	295 ± 6
Limousin[1]	11.9 ± 0.2	280 ± 7
Tropical composites[2]	21.7 ± 4.0	330 ± 46
Brahman[2]	25.0 ± 4.7	334 ± 45

[1] Laster *et al*. (1972).
[2] Johnston *et al*. (2009).

POST-PARTUM RESUMPTION OF CYCLICITY AND RECONCEPTION

The interval from calving to first ovulation, the post-partum anoestrous interval (PPAI), is ~50–60 days. The aim is to have cows conceive while lactating. For cows to calve every 12 months, conception needs to occur 75–80 days after calving. The PPAI in many cows exceeds this and prolonged PPAI is particularly evident in many northern herds (Entwistle 1983).

Physiology of resumption of cyclicity post-partum

Post-partum anoestrus is a normal physiological event (Senger 2003). Immediately after parturition the myometrium (uterine musculature) undergoes strong repeated contractions to facilitate discharge of conceptus fluids and membranes from the uterus. These contractions compress the uterine vasculature, minimise haemorrhage and simultaneously reduce the overall size of the uterus. Suckling initiates oxytocin release from the posterior pituitary in the brain, which is important not only for milk ejection but for continued uterine contraction. Parturition in beef cattle occurs in a non-sterile environment, resulting in bacterial contamination of the reproductive tract. Normal post-partum events eliminate bacterial contamination within days but conditions such as dystocia and retained foetal membranes predispose the uterus to infections, thus delaying involution of the uterus (Chapter 13). Under most circumstances uterine involution (return of the uterus to a normal non-pregnant state) is completed by ~30 days in the beef cow.

Early post-partum, there is a transient rise in follicle-stimulating hormone (FSH) concentrations which precede emergence of a follicular wave (Crowe *et al.* 1998). Only a small proportion of beef cows ovulate the first dominant follicle after parturition but most likely this dominant follicle will undergo atresia. Recurrent increases in FSH occur every seven to 10 days and each is associated with emergence of a follicular wave. The ability of follicles to continue to grow and become dominant depends on the level of pulsatile luteinising hormone (LH) secretion, which in turn is dependent on the level of tonic GnRH secretion. High-frequency pulsatile LH secretion stimulates both the continued development of a dominant follicle and the secretion of oestradiol by this follicle to levels sufficient to induce a pre-ovulatory LH surge. On average in beef cattle, the third dominant follicle after calving is ovulated. This is followed by an oestrous cycle of short duration characterised by the development of one dominant follicle, which is subsequently ovulated, and is then accompanied by a cycle of normal duration. Anoestrus in the post-partum beef cow occurs due to failure of ovulation of a dominant follicle rather than failure of a dominant follicle to develop (Stagg *et al.* 1995).

Factors affecting post-partum anoestrous interval

The main factors affecting PPAI, reviewed comprehensively by Montiel and Ahuja (2005), are suckling and pre- and post-partum nutritional status (reflected by liveweight and body condition). Other factors such as breed, age, number of calvings, milk yield, calving season, presence or absence of the bull, delayed uterine involution, dystocia and general health status all influence PPAI but, as Wettemann (1994) stated, any factor considered as a probable cause of PPAI other than nutrition and calf presence, only modulates the effects provoked by those two major factors.

Suckling and lactation

Lactation status of the cow exerts most probably the greatest influence on subsequent fertility (McGowan and Lane 2003). Unlike dairy cows, suckling occurs throughout lactation in beef cattle until weaning. Maternal bonding and suckling are crucial factors in affecting PPAI in beef cattle (Garcia-Winder *et al.* 1984; Stagg *et al.* 1998). The suppressive effects of the calf's presence on LH secretion and the timing of the first post-partum ovulation are independent of the neurosensory pathways within the teat and udder (Williams *et al.* 1993; Hoffman *et al.* 1996). Maternal–offspring bonding is a crucial factor in the suckling-induced suppression of LH secretion and hence a major cause of lengthening the PPAI (Stagg *et al.* 1998). Both sight and smell are used by the cow to identify the calf, therefore both those senses need to be removed to decrease the suppressive effect of suckling on LH secretion (Griffith and Williams 1996).

Pregnancy rates of lactating cows are invariably less than those of non-lactating cows, with this difference more marked in first lactation cows due to the concurrent demands for maternal growth and lactation. There are interactions between breed, age, lactation status, body condition and liveweight, with lactating cows usually in poorer condition and of lower liveweight than non-lactating cows. This difference is more apparent in *Bos indicus* than in *Bos taurus* breeds. The issue of lower reproductive rates in first lactation cows is more marked in northern than in southern Australia, reflecting both the predominance of *Bos indicus* breeds and the harsh nutritional conditions, particularly during the dry season (Entwistle 1983). Johnston *et al.* (2010) found that the mean PPAI was 134 days in Brahman three-year-old first lactation cows and that only 53% of these young cows had their first ovulation before weaning of their calf. For lactating four- and five-year-old mature cows, the PPAI on average was 66 and 40 days, with 81% and 93% recording an ovulation before weaning.

It is not clear whether lactating cows have lower pregnancy rates because of lactation *per se*, because of additional nutritional requirements to maintain liveweight or as a result of the interaction. Undernutrition contributes to prolonged PPAI, particularly in cows in pasture grazing situations where forages do not meet their feed requirements. It is also uncertain if lower pregnancy rates in lactating *Bos indicus* cows than in *Bos taurus* cows are a symptom of reproductive inefficiency or a reflection of an inherent survival mechanism, particularly during the dry season.

BCS at the time of calving

The relationship between BCS at calving and subsequent pregnancy rates is strong, PPAI being 43 days longer for each unit of BCS less at calving (Wright *et al.* 1987). A minimum BCS of 2.5–3 at calving is required to ensure acceptable post-partum reproduction through shorter PPAI, higher pregnancy rates and shorter intercalving intervals in both *Bos taurus* (Richards *et al.* 1986;

Makarechian and Arthur 1990) and *Bos indicus* breeds (Montiel and Ahuja 2005). A summary of eight trials in tropical regions found that cows with a BCS of ≤2 at calving had 60% pregnancy rates compared to 91% in cows with a BCS of ≥2.5 (McGowan and Lane 2003). More detailed work (Mayer *et al*. 2012) from 7200 cow-years from six sites in northern Australia highlighted the effect of lactation and body condition mid-mating on number of cows conceiving per cycle. With lactating cows there was a curvilinear increase in the number of conceptions per oestrous cycle with increasing BCS, while in non-lactating cows, conception rates per cycle plateaued at a BCS of ~2.5.

In many situations it is not feasible to determine BCS at calving or during the mating period. Similar trends were demonstrated at an annual pregnancy test in August, several months before calving (McGowan *et al*. 2013), where cows in poorer condition in the months before calving had significantly lower pregnancy rates in the next breeding season (Fig. 14.3). The difference was less evident in the lower carrying capacity lands of north Queensland, the Northern Territory and northern parts of Western Australia compared with the more productive regions of central Queensland, southern Queensland and western Queensland.

While BCS is a subjective trait and is somewhat indicative of fat reserves, measurement of P8 fat depth by ultrasonography gives a more precise relationship between body composition and subsequent pregnancy rate. This was demonstrated in first lactation Brahman cows in the Northern Territory, where there was a curvilinear response between P8 fat depth three months before first calving and subsequent pregnancy rate (Fig. 14.4). Pregnancy rates increased >10% unit for each 1 mm increase in fat between precalving fatness of 5–10 mm but outside those ranges the increases in pregnancy rates for each 1 mm increase were smaller (Schatz 2011).

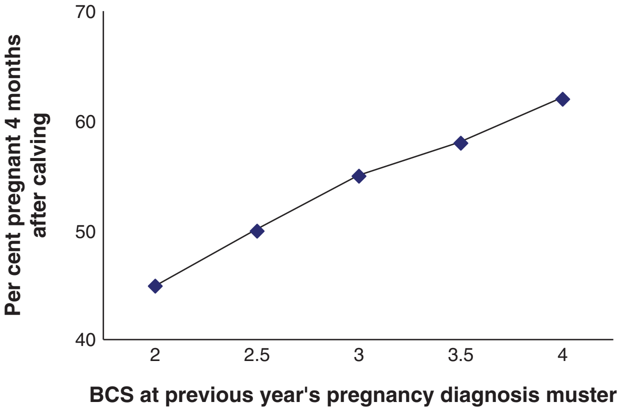


Figure 14.3: The relationship between cow BCS at the previous year's muster and pregnancy rates of cows four months after calving. Source: McGowan *et al.* (2013).

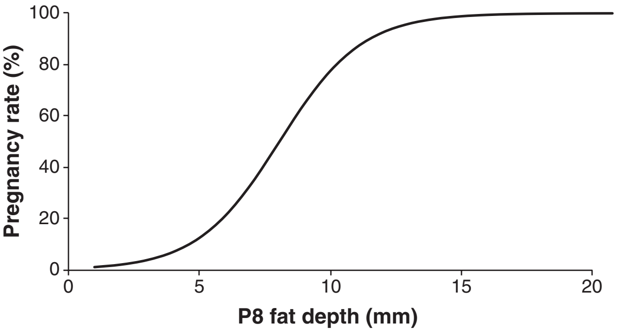


Figure 14.4: The relationship between P8 fat depth three months before calving and subsequent pregnancy rates of first lactation cows. Source: Schatz (2011).

Management practices to shorten PPAI

Manipulating and controlling the severity of PPAI of cows is important in improving reproductive performance, particularly in northern beef herds. There are essentially two approaches: increasing the nutrient supply to the cow by improved pastures or supplementary feeding, or reducing the nutrient drain on the cow by supplementary feeding of the calf or removing it at a young age. Both approaches aim to reverse tissue nutrient loss during late pregnancy and in lactation, thus permitting ovarian activity to resume sooner after calving (Entwistle 1990).

Pre- and post-partum nutritional status

The level of nutrition both pre-partum and post-partum affects follicular development, but level of feeding pre-partum is more important for determining PPAI than the level post-partum (McGowan and Lane 2003). Pre-partum nutrition is most important because of the direct effects of nutrition on the ovary as well as on brain hormone regulators (Scaramuzzi *et al*. 2011). The period from primordial follicle recruitment to ovulation is at least five months and nutrition can influence folliculogenesis and oocyte development throughout. This is part of the reason for the strong relationship between pre-partum, and to a lesser extent post-partum, BCS and liveweight with pregnancy rates.

Spike feeding is high-energy supplementation of late pregnant cows for six to eight weeks pre-partum. The long period of nutritionally influenced follicular development explains how spike feeding reduces PPAI particularly in

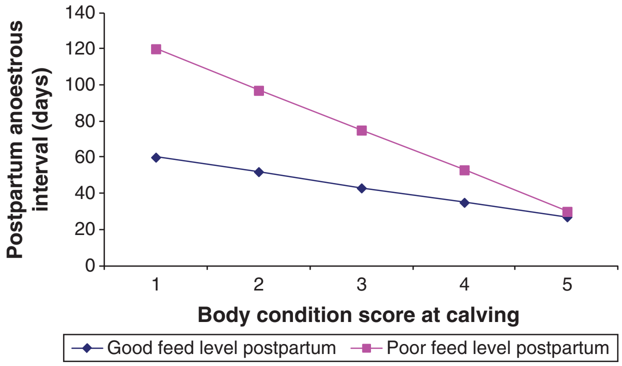


Figure 14.5: The effect of post-partum level of feeding and cow BCS at calving on PPAI. Source: Graham (2011).

first lactation *Bos indicus* cows, without having a marked effect on body condition or liveweight (Fordyce *et al.* 1997). This effect may reduce PPAI by stimulating ovarian function and perhaps by reducing the negative feedback effect of oestrogen (Fitzpatrick 1994).

The effects of post-partum nutrition on the length of PPAI in *Bos taurus* cows are illustrated in Fig. 14.5. Cows with poor feed level post-calving have a prolonged PPAI (Graham 2011) and cows with a BCS of ≥2.5 are less likely to respond to improved post-partum nutrition than thinner cows (Short and Adams 1988; Wright *et al.* 1992). However, in *Bos indicus* cows the effects of post-partum nutrition are inconsistent through interactions with milk yield and suckling intensity (Jolly *et al.* 1996). This inconsistency may reflect interactions among pre- and post-partum nutrition, negative energy balance, BCS, milk yield and suckling as well as other environmental factors that influence duration of PPAI.

Reducing the suckling period

The effect of suckling, particularly in *Bos indicus*, appears to be related to the suckling frequency rather than the nutrient drain from the cow. It is possible to reduce PPAI by restricting the suckling period to several hours per day (Randel 1981). In many countries with a predominance of *Bos indicus* cattle, cows are milked for human use as well as the calves being allowed to suckle. This is where separating the calf for several hours each day is feasible. Generally, under Australian conditions, the ability to manipulate PPAI during lactation by restricted suckling is limited as it requires managerial intervention.

Creep-feeding is a system of supplementing calves during lactation, which may reduce the suckling stimulus and trigger resumption of cyclicity. Calves can be separated from the cow by use of a creep panel or an automated drafting system (Fordyce *et al.* 1996a). The fertility responses in terms of improving pregnancy rates have been inconsistent (Schlink *et al.* 1988; Fordyce *et al.* 1996a).

Temporary weaning is short-term calf removal for up to six days. There is an increase in pulsatile LH secretion two to six days after removal of suckling stimulus. The acute response to weaning can be markedly attenuated by the premature return of calves and it may require up to six days for all cows to respond to temporary weaning. The responses of temporary weaning in reducing PPAI and increasing pregnancy rates have been equivocal (Montiel and Ahuja 2005). Temporary weaning has achieved significant responses in some situations where cows are in average or good condition but it would seem to be only a chance effect.

An alternative to temporary weaning is the use of nose plates in calves at ~10 weeks of age for two weeks to inhibit suckling. The responses in reducing PPAI have been equivocal (Quintans *et al.* 2009; de Castro *et al.* 2011). Should temporary weaning trigger ovarian activity, the first oestrus after calving is often short and relatively infertile. The only time that temporary weaning is recommended is in conjunction with specific oestrous synchronisation methods (i.e. using progesterone therapy in artificial breeding programs for lactating cows; Fahey *et al.* 2000).

Cessation of suckling (i.e. weaning) will trigger resumption of ovulation in anoestrous cows but the duration is variable. Cows with BCS of ≤2.5 at calving, which had their calves weaned at 70 days post-partum, ovulated within 50 days of this (Jolly *et al.* 1996). In many *Bos indicus* cows this period is considerably longer particularly in younger cows. Johnston *et al.* (2010) reported that in anoestrous cows that had been suckled for four to six months then weaned, the average number of days from weaning until first ovulation was 99, 74 and 76 days for three-, four- and five-year-old cows respectively. The effect of weaning on reducing PPAI was greater than that of post-partum supplementation (McSweeney *et al.* 1993).

WEANING

Weaning is the permanent separation of cow and calf, and is stressful for both. While calves may be locked in a secure yard, cows continue to call for their calves for some days and try to return to the yards. Typically, cows are moved as far away as feasible so they cannot hear the calf, thus lessening their attempts to return. A less stressful strategy is to leave the cows close to the yards for three to four days after weaning, after which they are more manageable to move to paddocks (Tyler *et al*. 2012).

The main benefits of weaning to the cow are that it preserves body condition, minimises weight loss and thus increases survival. The reproductive benefit should be aimed at ensuring cows have a better ability to conceive during the next mating, not as a means of increasing conception rates, thus out-of-season calvings, this mating which could occur in continuously mated herds. Weaning calves at a younger age (reducing the length of the suckling period) will help keep cows in better body condition. This applies to all classes of country but on good country, cows are generally in better condition and therefore some weight loss may be acceptable. On poorer country cows are invariably lighter in condition and loss of body condition during lactation is more critical in terms of survival and reconception. Flexibility in weaning times is critical for managing times of low rainfall (Tyler *et al*. 2012). In *Bos indicus* cows, early weaning of calves at two to three months of age reduced weight loss and body condition during the dry season and increased pregnancy rates in some herds, but responses vary widely (Schlink *et al*. 1988, 1994; Sullivan *et al*. 1992).

Mating systems, type of country, seasonal conditions, time of year, age of breeders and target markets (Chapter 12) are considerations in planning weaning strategies. The duration of mating determines numbers and spread of calves and thus their subsequent management post-weaning; a longer mating period usually leads to more calves that are younger and thus lighter at weaning. In continuously mated herds with year-round calving, two rounds of weaning reduce the number of cows that are lactating for long periods, particularly over the dry season. In restricted-mated herds with a three- to five-month calving period, usually only one weaning is required but some later-born and thus lighter calves at weaning will require preferential management (Tyler *et al*. 2012).

Post-weaning care of weaners is critical for the success of a weaning program. Weaning is stressful for the weaner: key factors in managing stress include matching the appropriate nutrition to the age of the weaner, segregating weaners on size, regular and calm handling, treating parasites, vaccinating against relevant diseases and close monitoring, particularly in the first one to two months post-weaning (Chapters 13, 16).

PREGNANCY DIAGNOSIS IN BEEF CATTLE

Rectal palpation and ultrasonography are the most popular and effective methods of pregnancy diagnosis and foetal ageing (estimating days/months pregnant at time of examination). In intensively managed beef herds, ultrasonography is more common, allowing very early pregnancy detection and very accurate foetal ageing. In extensive beef herds, rectal palpation is the most common method because of the wide range of pregnancies that can be present, particularly in herds mated year-round.

Rectal palpation involves palpation of the uterus, foetal membranes and foetus through the rectal wall. An experienced operator can diagnose pregnancy 28–35 days after conception. The accuracy of ageing the foetus is at greatest at 35–65 days of gestation then decreases with advancing pregnancy. For animals <5 months pregnant, the estimate of foetal age has an error of ± 0.5 months and for those ≥5 months pregnant, the error is ± 1 month. Both accuracy of pregnancy diagnosis and ageing of the foetus are influenced by operator skill, quality of infrastructure, temperament of cattle and management of cattle before testing.

Brightness mode (B-mode) real time ultrasonography is best suited for pregnancy diagnosis in cattle. A variable-frequency linear or sector scan transducer (probe) is inserted into the rectum. The high-frequency probes (5–10 MHz) can detect the embryo, foetal membranes, foetal heartbeat and foetal structures. Ultrasonography can more accurately determine ovarian function (cyclicity) by scanning the ovary for follicles and corpora lutea (Shephard 2005). Ultrasonography can replace or complement rectal palpation for the early determination of pregnancy. The advantages of ultrasonography include reduced risk of trauma both to the foetus and to the operator if an extender on the probe is used, and improved ability to diagnose pregnancy. The embryo and foetal membranes can be detected at 20–22 days in heifers and 25–28 days in cows. The age of the foetus can be accurately calculated by measuring the crown–rump length of the foetus and the best accuracy for ageing of the foetus using several parameters is 35–100 days. Twins can be diagnosed and sex determined at 55–80 days with higher-frequency probes (7.5–10 MHz) and at 70–120 days with lower-frequency probes (5 MHz).

Pregnancy diagnosis information can be used immediately or later for more efficient management of cattle (Jephcott and Norman 2004) by:

- the early detection of non-pregnant heifers and cows. This gives immediate indication of current

reproductive status, such as the total number of pregnant females for various classes of cattle and how readily the females conceived. Heifers that are pregnancy-tested six weeks after bull removal should have at least a 90% pregnancy rate, with most heifers conceiving in the first two cycles (six weeks). Similarly, lactating cows should have at least a 70% pregnancy rate. Anything less suggests impaired reproductive performance;
- better prediction of calving date (Matthews and Morton 2011);
- making phenotypic and genetic improvement in reproductive performance by retaining pregnant animals and culling empty animals;
- accurately selling stock on reproductive status as pregnancy-tested in calf (PTIC) cows may attract a premium;
- segregating stock on pregnancy status. The nutritional requirements of heavily pregnant cows are vastly different from those of early pregnant cows. Pregnant cows in poor condition are a survival risk (Tyler and Fordyce 1988);
- allowing accurate budgeting of herd structure, sales and stocking rates;
- improving control, prevention and treatment of reproductive diseases through examination of dates and numbers of conceptions;
- assisting in the diagnosis of bull fertility problems.

Ideally, pregnancy diagnosis should be done 22–35 days after mating with ultrasonography or 35–50 days if using manual palpation only. In year-round mated herds, pregnancy diagnosis should initially be conducted three to four months after anticipated peak conception time; for northern herds pregnancy diagnosis would be March to May. A second pregnancy diagnosis, August to October in year-round mated herds, allows assessment of pregnancy status in cows non-pregnant at the previous examination.

Improper rectal palpation can result in rupture of the foetal membranes and embryonic death, particularly when cattle are examined before day 35 of gestation. When performed correctly, it does not increase the incidence of embryonic mortality (McGowan and Lane 2003). The Australian Cattle Veterinarians (ACV) has an accreditation scheme for pregnancy-testing for veterinarians as well as a trademark on tail tags identifying PTIC females. The scheme is audited and pregnancy testers must pass a proficiency exam to gain accreditation.

PREGNANCY PREVENTION

In extensive herds there is often difficulty in controlling the movement of bulls. Preventing pregnancies in surplus females significantly reduces breeder mortalities by avoiding out-of-season calving and enables producers to fatten those females for sale. Spayed (sterilised) females can continue to graze with the breeding herd until turnoff, thus reducing mustering and handling. For the northern live export trade surplus females have to be spayed or guaranteed non-pregnant, which requires two examinations. Pregnancy prevention is by permanent sterilisation via surgical methods (spaying) or temporary impairment of fertility by immunosuppression.

Spaying

The only method of reliably and permanently preventing pregnancy is through surgery. Spaying involves severing the ovaries from their attachments, and webbing is where a portion of the fallopian tube is removed. There are three methods of spaying: the dropped ovary technique (DOT), flank spaying and passage spaying. Spayed females abort if <135 days gestation but may carry the pregnancy if spayed later than this. Surgical techniques and the advantages and disadvantages of each method of spaying are described by Letchford (2010).

DOT, as described by de Witte *et al*. (2006), involves surgery via the vagina: a Willis ovariotome or probe is inserted into the caudal peritoneal cavity via the dorsal fornix of the cervix. Each ovary is inserted into the head of the probe using the other gloved hand inserted in the rectum, severed and allowed to drop into the peritoneal cavity. It is a procedure more suited to heifers than cows. There is no external incision and thus no hide damage, and there can be a high throughput (60–70 h) in the hands of a skilled operator. The technique cannot be used for webbing and cannot be used in recently calved or mid to late pregnant cows because of difficulty in locating and manipulating the ovaries and the risk of mortality due to surgical haemorrhage.

Flank spaying is a left flank surgical approach through the paralumbar fossa. The operator locates either the ovaries (to spay) or the fallopian tube (to web). These are severed internally using a tool with a concealed scalpel blade (Spaymate), removed and the skin sutured. Females of all ages and stages of pregnancy can be flank spayed. There is hide damage and a greater risk of infection than with DOT.

Passage spaying is a surgical approach through the dorsal wall of the vagina using a dilator and small surgical blade. The hand is inserted to locate the ovaries or fallopian tubes, which are severed using a Spaymate. Passage spaying can be difficult in heifers as they are smaller in size. There may be post-operative vaginal, uterine or peritoneal infections but there is no hide damage.

Webbing by either flank or passage spaying causes minimal haemorrhage and thus lower mortalities than spaying; there is retention of the foetus irrespective of age of pregnancy but females continue to show oestrus post-calving. The decision to spay or to web is often not made until the stage of pregnancy is determined upon entry of the peritoneal cavity.

Mortalities of 1.5% and 2.5% occur with DOT and flank spaying respectively, with most occurring within four days of spaying (McCosker *et al.* 2010). DOT and flank spaying cause similar levels of acute pain, but adverse effects on welfare as assessed by behavioural and physiological responses were greater for flank spaying than for DOT (Petherick *et al.* 2013).

It is difficult to provide an exact figure on the number of females that are spayed annually but it would be several hundred thousand. One highly skilled, experienced veterinarian performs the DOT on 20 000 cattle and flank spaying on 5000 cattle per annum (Petherick *et al.* 2013).

Immunosuppression

Reversible suppression of fertility can be achieved in bulls and females by use of GnRH agonists either via implant or immunisation against GnRH using a two-dose protocol. The GnRH agonist, deslorelin, administered as a subcutaneous implant is effective in inhibiting ovulation for 200–300 days depending on the dose rate (D'Occhio *et al.* 2002). These implants are currently not registered for use in cattle.

Although never widely used, immunisation against GnRH was available as Vaxstrate® and was effective in suppressing ovarian function in heifers and cows for up to six months, beyond this there was a variable return to normal cyclicity (D'Occhio 1993). Vaxstrate® was withdrawn from the market principally because of poor uptake by the extensive cattle industry as it required two vaccinations four to 16 weeks apart to be effective. A recent product, Bopriva®, using a slightly different formulation, is registered for behavioural modification through suppression of standing oestrus and reduced aggression in feedlot animals. It also has a variable post-pubertal immunological suppression of ovarian and testicular function (Oswin 2011).

Growth rates of spayed females

There is a perception by producers that spayed heifers have greater liveweight gains and increased subcutaneous fat than entire heifers. This is not supported by experimental work (Saul *et al.* 1982; Jeffery *et al.* 1997). McCosker *et al.* (2010) found that liveweight gains in heifers after spaying were reduced for up to six weeks compared to entire heifers. From time of flank spaying at 15 months of age to slaughter at 30 months of age, growth was greater for entire heifers (0.36 kg/day) than spayed heifers (0.32 kg/day), with only minor differences in carcass attributes (Jeffery *et al.* 1997).

LOSSES FROM FERTILISATION TO WEANING

Reproductive losses in cattle can be partitioned into the following areas with some indication of magnitude (Burns *et al.* 2010):

- females not pregnant at the end of the breeding season (10–40% of all cows);
- pre-natal mortality – losses from about day 45 of pregnancy to start of parturition (2–8%);
- peri-natal losses – losses from parturition to 48 h later (2–12%);
- post-natal losses – losses from 48 h after calving to weaning, which typically occurs around five to seven months of age of the calf (1–15%).

In extensive herds with infrequent inspection, it is often difficult to differentiate between pre-, peri- and post-natal losses. Pregnant females may present at the next muster, which may be many months later or next year, as non-lactating. Losses are then described as those happening from confirmed pregnancy to weaning. Estimates of 'acceptable' levels of loss from confirmed pregnancy (about day 45) to weaning range from 5–12% (Holroyd 1987; Burns *et al.* 2010) with the latter estimates made up of 5% pre-natal, 4% peri-natal and 3% post-natal. While no loss is desirable, 'acceptable' is a benchmark below which attempts to reduce mortalities, given the range of causative factors, may not be feasible or economically viable (Burns *et al.* 2010).

Females not pregnant at the end of the breeding season

These females represent the major area of loss due to factors such as breed, age, environment, disease and poor BCS. Empty cows represent 10–40% of the herd but can be as high as 90% in poor conditioned first lactation *Bos* *indicus* cows. Losses can be partitioned into failure to ovulate (i.e. post-partum anoestrus), failure of fertilisation and embryonic mortality (McGowan and Lane 2003).

Fertilisation failure is the number of ova that fail to be fertilised; accurate estimates can only be made by flushing the reproductive tract of cows soon after copulation. An 'acceptable' level of fertilisation failure is ~10% although fertilisation failure rates >10% could occur in extensive situations (Burns *et al.* 2010). Part of the reason for fertilisation failure could be the lack of opportunity to mate through herd dispersion effects, bulls with poor libido or structurally unsoundness.

Embryonic mortality can be divided into two stages. Early embryonic mortality (EEM) is from fertilisation until about day 24 and accounts for 75–80% of embryonic loss with the greatest proportion of these occurring 8–18 days after fertilisation (Burns *et al.* 2010). Late embryonic mortality (LEM) occurs from about day 25 to day 42 and coincides with the time of implantation when the fertilised ovum (blastocyst) and placental membranes attach to the endometrium. These combined levels of fertilisation failure and early embryonic loss result in a 'biologically normal' first cycle pregnancy rate of ~60% (McGowan and Lane 2003). Cattle with EEM show no clinical signs other than a return to oestrus at the normal time of 19–22 days after the previous oestrus. Cattle with embryonic loss after day 16 have a delayed and often variable return to oestrus because of the presence of a CL but usually return ~12–40 days later (McGowan and Lane 2003). This ovulation may not be associated with behavioural signs of oestrus. High levels of embryonic mortality may be suspected when there is a decreased proportion of females calving in the first six to nine weeks, in the absence of other causes such as poor BCS at time of mating.

Causes of embryonic mortality, summarised by McGowan and Lane (2003), include the following factors:

- genetic factors, which are considered a significant cause with estimates of ~10% of all embryos having some form of chromosomal abnormality;
- environmental factors such as deficits in energy and excessive intake of rumen degradable protein and non-protein nitrogen (Chapter 16) have been inconsistently linked with increased levels of loss. An increase in body temperature at mating has been consistently associated with increased levels of embryonic mortality;
- infectious diseases can be a major cause of embryonic mortality. Bovine viral diarrhoea virus (BVDV) or pestivirus causes direct infection and death of the embryo while *Campylobacter* (Vibrio) organisms pass through the cervix after coitus, multiply and invade the endometrium and oviduct causing a mild inflammatory response preventing placental attachment (Lew-Tabor 2010; Chapter 13);
- rectal palpation has been associated with embryonic loss, but if performed correctly the procedure is not a cause;
- sperm abnormalities such as proximal cytoplasmic droplets and craters and vacuoles in the head piece may initiate fertilisation but the embryo subsequently dies. DNA chromatin aberrations in sperm have been associated with embryonic mortality (D'Occhio *et al.* 2007);
- other miscellaneous factors including transportation, ingestion of plants containing phytoestrogens and high levels of nitrates, severe weather conditions, micronutrient deficiencies and reproductive tract pathology.

Pre-natal losses

Losses of the foetus (abortion) in healthy animals from ~45 days of pregnancy to term tend to be in the range of 2–8%. A certain proportion of embryo-foetal loss is normal and represents the elimination of non-viable embryos or foetus such as those with abnormal chromosomes (David *et al.* 1971). For pre-natal losses, 45% occur in early, 30% in mid and 25% in late gestation (Holroyd 1987).

The causes of foetal loss are numerous (Radostits *et al.* 2000; Chapter 13) but can be broadly divided into infectious and non-infectious in origin (Jonker 2004). The main infectious causes are the bacteria *Campylobacter* and *Leptospira*, with fewer reported cases due to *Listeria*, *Salmonella* and *E. coli*. BVDV, bovine ephemeral fever and Akabane virus are the main viral causes of embryonic and foetal loss in Australia. Other important causes of abortion have been associated with *Neospora* and *Trichomonas*, both protozoan parasites.

Non-infectious causes of abortion are numerous and can be listed broadly as:

- genetic due to chromosomal abnormalities, inherited lethal congenital abnormalities and sire effects due to specific sperm abnormalities;
- deficiencies of selenium, vitamin E, iodine, manganese and copper have all been associated with loss, as has excessive intake of non-protein nitrogen such as urea;

- poisonings from plant phyto-oestrogens and nitrites, arsenic, lead and mycotoxicosis;
- environmental conditions such as high ambient temperatures;
- miscellaneous causes such as endometritis, twin pregnancies, infusion or insemination of the pregnant uterus, acute post-vaccination or therapeutic drug reaction and physical trauma.

Peri-natal and post-natal losses

Peri-natal losses are generally in the range of 2–12% (Burns *et al.* 2010) although extremely high losses have been reported. Dystocia rates in *Bos taurus* beef heifers may range from 20–40% (Norman 2006) although not all result in mortality, because of calving supervision and intervention by farm staff and veterinarians. Hill *et al.* (2009) reported 41% mortalities in peri-natal calves in a herd grazing Mitchell grasslands in north-west Queensland, attributed to gestational vitamin A deficiency. Post-natal losses range typically from 1–15% (Burns *et al.* 2010). A high proportion (44%) of post-natal losses occurred by 14 days after birth (Holroyd 1987). Other peak times of post-natal loss are around branding and weaning.

The causes of peri-natal and early post-natal mortalities are varied and often dependent on the management system. In extensive *Bos indicus* herds, losses due to dystocia tend to be lower than in intensive *Bos taurus* herds. Calf diarrhoea and septicaemia are common causes of peri-natal and post-natal death in intensive systems but not in extensive herds. Many losses in extensive herds are from unknown causes, reflecting the inability to observe cattle daily and remoteness from diagnostic laboratories. Many of these undiagnosed losses could be from causes similar to those associated with losses in intensive herds. Common causes of peri-natal and post-natal losses (Chapter 13) are:

- placental infections from leptospirosis, neosporosis, Akabane virus and BVDV;
- infections post-birth from coccidiosis, *E. coli* and viral infections resulting in diarrhoea and respiratory problems;
- dystocia, especially foetopelvic disproportion in heifers and high birth weight;
- extended periods of low rainfall causing mortalities of both cows and calves;
- high environmental temperature and humidity around the time of birth, especially in unadapted breeds;
- nutritional deficiencies such as copper and vitamin A;
- bottle teats, mustering and predation;
- abandonment by the cow when recording birth data, or poor mustering either by ground or aerial methods.

Calf diarrhoea and respiratory problems may not be apparent until three to four days after birth or even weeks or months later. These infections are more prevalent in intensive systems and older calves act as reservoirs of infection for young calves (Larson 2006). To maximise calf immunity and minimise exposure to pathogens, specific attention should be focused on the following (Larson 2006):

- ensuring adequate transfer of colostral immunoglobulins. Delayed suckling is the commonest cause of failure of passive transfer of immunoglobulins in colostrum, which are important for protection from disease;
- minimising dystocia and as a consequence delayed suckling;
- limiting environmental contamination with pathogens by older calves;
- calving heifers earlier in the calving season than mature cows to reduce exposure of their calves to pathogens, as heifers produce less colostrum with lower concentrations of antibodies than that of mature cows.

The prevalence and severity of calf disease will typically increase and the age at disease onset will decrease as the calving season progresses. This is because of the role that calves play as biological amplifiers of pathogens. Calves born later in the calving season are exposed to increasing levels of pathogens. The tighter the age distribution of calves within a group, the more this biological amplification is negated. The core components of an effective intervention program to prevent calf mortality are dispersal of livestock to maximise hygiene and enforced age segregation of neonatal calves (Larson 2006).

DYSTOCIA

Dystocia (calving difficulty) is an abnormal or difficult parturition. If there is no human intervention, there is invariably death of the calf and cow. Dystocia predominantly occurs in heifers, particularly heifers calving at two years of age with ranges in any year of up to 40% in some herds, although 20% is deemed the average. The prevalence in mature cows is ~3–5% (Norman 2006).

Dystocia is a lesser issue in *Bos indicus* than in *Bos taurus* breeds or crosses with the large European breeds (Morris 1980). This may reflect smaller calf birth weights in *Bos indicus* breeds (Frisch 1973) as well as initial calving at three years rather than at two years of age. *Bos indicus* cattle generally occur in areas with lower levels of nutrition during late pregnancy and hence reduced calf birth size. There is a small degree of natural selection operating under extensive conditions where dystocia generally results in death of both cow and calf (Entwistle 1983).

Dystocia and its proportional contributions can be classified as posterior presentation of the foetus (35%), ineffective labour (15%) and foetopelvic disproportion (50%), which is an incompatibility between the size of the foetus (too large) and the size of the maternal pelvis (too small) (Norman 2006). It is important to distinguish whether the dystocia is caused by physiological or ineffective labour rather than by foetopelvic disproportion. Contributing physiological factors to ineffective labour are deficiencies in pre-calving oestrogen production as well as a suite of mineral and trace elements including calcium, phosphorus, copper, cobalt, selenium, iodine, sodium, zinc, magnesium and manganese, although the evidence in some cases is tenuous (Norman 2006).

Management of dystocia

There is debate as to the effects of nutrition, season, age of heifer at calving and pelvic area on reducing dystocia. High calf birth weight and male calves are the only factors that appear to be unequivocally linked with a higher prevalence. Selection of sires with low birth weight estimated breeding values (EBVs) for maiden heifers is the single most important management strategy to reduce dystocia. Several short-term (managerial) and long-term (genetic) solutions have been tried with varying success to minimise dystocia (Norman 2006).

- Use of half-sib or littermate sires – heifers are joined to bulls born in the same calf crop. It is essential that the selected bulls be from dams of unassisted birth and are of below or average birth weight. This supposedly ensures that the bulls are genetically compatible, but the technique is regarded as a possible 'quick fix' in commercial herds.
- Visual appraisal – there is no scientific evidence that visual selection based on shoulder and pelvis conformation is effective in reducing dystocia. External measurements of the pelvis do not reflect internal pelvic area.
- Use of crossbred heifers – heterosis affects calf birth weight, and calf birth weight can be significantly controlled by the dam such that dystocia in Brahman cows even bred to bulls of different breeds still tends to be low. The converse does not apply with Brahman-sired calves from Hereford dams. Heterosis also affects heifer pelvic area, with Brahman crossbred heifers having increased pelvic areas compared to purebred contemporaries. Importantly the heifer, rather than the calf, should be the crossbred animal as heterosis will lead to increased birth weight (Chapter 17).
- Growth rate from weaning to mating – females on a higher plane of nutrition reach puberty earlier, thus conceiving earlier and calving earlier although the reasons for reduced dystocia in earlier calving heifers is not clear.
- Nutrition during pregnancy and body condition at calving – the ideal appears to be for a steady growth of 0.5–0.75 kg/day during gestation although, in heifers, diets high in protein and energy during the second trimester of gestation increased calf birth weight, with an associated increase in dystocia (Micke *et al.* 2010). During the last trimester of pregnancy, the foetus gains ~80% of its final weight; increased metabolisable energy levels at this stage can increase calf birth weight although this is not generally associated with increased dystocia or calf mortality. Conversely, restricting nutrition during the last trimester may reduce calf birth weight and muscular contractions thus parturition may be adversely affected. Except for extremes, attempts to reduce dystocia by manipulating nutrition during late pregnancy, in isolation from the rest of gestation, invariably fail. There are suggestions that 'ineffective labour' at calving is associated with overfat heifers. Possible causes are an inability to mobilise calcium and other minerals as well as the accumulation of fat around the vagina decreasing its mechanical ability to dilate. Fat *per se* does not cause physical obstruction of the birth canal but there is an increase in myometrial fat reducing tone and contractility.
- Exercise during pregnancy – while not supported by scientific evidence, increasing exercise in pregnant heifers is believed to help reduce dystocia by minimising overfatness and thus improving uterine and abdominal muscle tone. Some producers in southern Australia feed hay on hilltops, well away from watering points, to ensure heifers have adequate exercise during pregnancy (Kroker and Clarke 2000).
- Selection on pelvic area – pelvic area can be measured by a mechanical (Rice) or hydraulic (modified Krautmann) pelvimeter inserted into the rectum to measure the widest horizontal plane and the shortest vertical plane inside the pelvis (Norman 2002). The values are

multiplied to obtain the area. The aim is to increase the pelvic area to liveweight ratio (Norman 2002). The use of pelvimetry in heifers and bulls is controversial in reducing dystocia. In a southern Queensland study, heifers with significantly smaller pelvic areas, measured as yearlings, needed higher levels of assistance when calving as two-year-olds (Norman 2002). There is some imprecision using the Rice pelvimeter, suggesting that the technique is more suited to group selection than to identifying individuals requiring assistance at calving;

- Objective bull selection – there is limited Australian work to determine the effect of minimising dystocia by measuring pelvic area of bulls. However, as pelvic area is moderately heritable in *Bos taurus* breeds (Glaze *et al.* 1994), mating bulls with larger pelvic areas to the mature cow herd will proportionally increase the number of heifer progeny with a larger pelvic area. Genetic selection through Breedplan offers a longer-term but more permanent method of reducing dystocia. EBVs are available for calving ease, calculated from calving difficulty score, birth weight and gestation length data.

CULLING FEMALES

Eventually females are removed from the herd as surplus to requirements or culled for poor reproductive performance, age or physical defects. Culling rate and replacement female selection rates are interrelated, as sufficient numbers of replacement females must be produced to allow selection and to balance numbers in a stable herd situation. As herds are intentionally increased or reduced, rates of culling and retention need to be adjusted accordingly. Culling rate is determined mainly by numbers of heifer progeny retained and a high culling rate in a stable herd is only possible with high weaning rates (Manning 2004). A high culling rate shortens the generation interval and increases genetic gain; it removes poorly performing cows and keeps herd age relatively young, thus minimising natural attrition from conditions such as grass tetany, eye cancer and bottle teats.

The percentage of females sold from a herd gives an indirect measure of female mortality in extensive herds, with a low proportion of female sales indicating high female mortality rates. Sales of surplus females are an important source of income (Niethe and Holmes 2008) and heavier older cows sell at a premium. Often culled females are not suitable for sale because of pregnancy and poor body condition. Prevention of pregnancies by surgical spaying to improve sale value has been discussed (above).

Culling for poor reproductive performance should be based on pregnancy status and an analysis of lifetime productivity. After about eight years of age, cows with deteriorating dentition have a poorer ability to forage and are a higher survival risk in drought (Fordyce *et al.* 1990). Culling is done commonly at weaning of calves. While it is desirable to cull empty lactating cows, the cost of culling all cows with poor reproductive performance can be high and may need to be spread over several matings. Cows should not be culled on body size as highly fertile cows may have smaller body size (Seifert and Rudder 1976).

SELECTION OF REPLACEMENT FEMALES

Selection of replacements is done primarily before mating and weaner heifers from the breeding herd are the main source. Purchasing pregnant females is an option providing the genetics, calving date and disease status match the breeding aim of the enterprise. In well-managed herds, 50–60% of weaner heifers are needed as replacement breeders, particularly with efficient culling procedures. Guidelines for precise numbers of replacements are provided by Fahey *et al.* (2000) and MLA (2011). Retaining too many replacement heifers can increase stocking rate; retaining too few does not allow balance in the breeding herd for size and age structure.

The selection criteria for replacements should be consistent with production objectives. The emphasis on different traits requires balance as single trait selection such as high growth rate may increase dystocia or reduce lactating cow reconception rates. Selection for various traits should use both the actual performance of the animal and its EBV (Chapter 17).

Pre-weaning growth is highly correlated with milk production of the dam (Hunter and Magner 1988) and has little genetic relationship with post-weaning growth in *Bos indicus* cross cattle (Fordyce *et al.* 1996b). Culling non-calving cows avoids keeping replacement heifers from cows that missed calving the previous year. These weaner heifers will be older and heavier at weaning and, without individual cow records, are more likely to be kept as replacements (Jeyaruban *et al.* 2011). In this way, poorer reproduction genetics will be multiplied through the herd (Johnston 2011). Pre-weaning growth is a valuable selection criterion as this phase is at least 25–40% of lifetime growth.

Post-weaning growth for animals in extensive herds is best assessed following at least a year's growth post-weaning (i.e. from weaning to the end of the following growing season). Growth in this period, especially in the six months following weaning, is partially affected by compensation for pre-weaning milk intake.

Heifers with physical abnormalities, poor temperament or other undesirable traits should not be selected. Lighter heifers, if they conceive, are early maturing animals. If only selecting the heaviest heifers, there is little pressure on them to perform if they are well above their critical weight at mating (Schatz 2012). Conformational traits are of doubtful value in predicting fertility (Fordyce and Cooper 1995). The possible exception is hip and rump shape. Rump angle and width are associated with calving ease; animals with high and narrow pin bones are more likely to have calving difficulty (McConochie 2007).

All selected heifers should be mated and, by six to seven months after start of mating, producers should identify and retain pregnant heifers, giving preferential selection to those that conceive early. All non-pregnant and all first lactation females that are dry the next year should be culled. Selection for fertility in females should be based on an ability to rear a calf to weaning. Producers should be cautious of culling smaller females later in life as many of them may be weaning calves annually.

In spite of low heritabilities for some reproductive traits, significant genetic progress for female fertility can be achieved from within-breed selection. Two experiments clearly demonstrate this; one with a Droughtmaster herd in north Queensland (Hetzel *et al*. 1989) and the other in a *Bos taurus* herd in New Zealand (Morris and Amyes 2005). In a Brahman herd in the Northern Territory, a combination of culling females that failed to wean a calf and selecting replacement heifers and bulls on traits such as fertility EBVs, scrotal size and semen quality was successful in improving conception rates in yearling heifers (Schatz *et al*. 2010), scrotal size (Schatz *et al*. 2011b) and pregnancy rates of lactating cows (Golding *et al*. 2011).

In selecting to improve fertility, decisions relating to culling and selection of replacements may be based on measurement of traits other than the primary traits included in the breeding objective (Burrow 2003). Indirect selection for traits such as scrotal circumference is likely to have greater impact on female fertility than is direct selection. There is an opportunity to improve reproductive performance of Brahman females through selection for reduced PPAI by selecting bulls with superior semen quality and sperm morphology (Johnston *et al*. 2012).

INFECTIOUS CAUSES OF REPRODUCTIVE LOSS IN BEEF CATTLE

Reproductive diseases strictly refer to any reproductive condition that impairs fertility and can be from a wide range of conditions:

- impairment of physical structure such as lameness, gait abnormalities and conformational abnormalities;
- defects of the reproductive tract such as testicular degeneration, penile abnormalities, preputial injuries, abnormalities of the cervix, uterus and ovary;
- infectious causes of loss, mainly from bacteria, viruses and protozoa.

By definition, an infectious disease is one that is capable of being transmitted from animal to animal with or without actual contact. A contagious disease is an infectious disease but the transmission is only by direct contact, droplet spread or contaminated objects such as clothing, towels or utensils. Although incorrect, the common usage of reproductive diseases refers to those that are infectious. The common infectious reproductive diseases in Australia are discussed briefly below, and more extensively in Chapter 13.

Vibriosis or bovine venereal campylobacteriosis (BVC)

This is an infectious venereal disease caused by the bacterium *Campylobacter fetus* subsp. *venerealis*. The generic name, *Campylobacter*, was previously known as *Vibrio*, hence the common name for the disease. The disease is widespread, particularly in extensive herds, and the most susceptible animals are replacement heifers. Branding rates in infected heifer groups are often only 50–70% of those in non-infected herds. Although most infected females eventually eliminate the infection, up to 10% may still be infected at the time of calving, with some becoming permanent carriers of the organism.

Bulls most commonly become infected by serving infected carrier females. Bulls less than four years of age are generally more resistant to becoming persistently infected than older bulls, but some young infected bulls remain infected for long periods. The infection in bulls is confined to the prepuce and produces no local or general symptoms. Spontaneous recovery in persistently infected bulls occurs rarely. In females, within a week of service by an infected bull, the *Campylobacter* organisms will have migrated through the cervix into the uterus and in ~25% of females will reach the oviducts. The most obvious clinical sign of infection is repeated return to service, the interservice interval often being prolonged to 28–35 days due to late embryonic mortality. 5–10% of infected females abort, generally between five and seven months of gestation. A small proportion of infected females may be rendered sterile due to bilateral infection of the oviducts. Females that have eliminated the infection are partly immune to reinfection and even when they do become reinfected their fertility is only marginally impaired.

Sampling of mated heifers provides the best opportunity for diagnosis. Vaginal mucus is collected by a veterinarian and the disease is confirmed in the laboratory by detection of *Campylobacter*-specific antibodies. In bulls, preputial or semen samples inoculated into a transport media can be cultured for the bacteria but this is not a reliable method. Bulls must be tested repeatedly to be confirmed free of infection. Advances in molecular diagnostic techniques offer promise for improved diagnosis. The bacteria can also be cultured from aborted foetuses. Vaccination of bulls and heifers is the most effective method of control. Norman *et al*. (2002), Hum (2007) and Lew-Tabor (2010) provide more detail on the disease.

Leptospirosis

Leptospirosis, or the common descriptor 'lepto', is a contagious disease of farm animals, rodents and wild animals. It can infect humans and is an occupational health hazard for farmers, veterinarians and abattoir workers. The disease is caused by the bacterium *Leptospira* and there are two serovars or types in cattle, *Leptospira pomona* and *L. hardjo*, that cause disease and reproductive loss. *L. hardjo* is the most prevalent type affecting cattle: a three-year survey of cattle in Queensland cattle found prevalence of antibodies to *L. hardjo* (35%) and *L. pomona* (17%) with *L. pomona* being more prevalent in low-rainfall areas (McGowan 2003).

The bacteria colonise the kidneys and, in females, sometimes the reproductive tract. The bacteria are shed in the urine or at abortion or birth, contaminating the environment. They can survive for some weeks in water and mud. Watering points and muddy areas around troughs are believed to be the main sites where transmission occurs in cattle at pasture. The organisms penetrate the mucous membranes of the mouth, nose and eyes and abraded skin. *L. hardjo* has adapted to long-term survival with a small proportion of infected cattle continuing to shed the organism in their urine for months, sometimes years. Carrier cattle are the major source of infection and probably the most common means by which infection is introduced into a herd. *L. pomona* is adapted to long-term survival in pigs (particularly farmed pigs) and therefore infections in cattle are considered incidental. Following natural infection, cattle are immune to reinfection but only to the serovar from which they were infected. The duration of immunity is approximately one to two years.

Many infections remain unnoticed although there have been severe outbreaks, usually due to the introduction of infected animals into previously unexposed or non-vaccinated herds. This results in a large number of abortions in mid–late pregnant cows and deaths in young calves. There are relatively few studies which convincingly demonstrate an association between *L. hardjo* infection and abortions, stillbirths, and the birth of weak calves. The evidence linking *L. pomona* to such losses is more solid; however, the prevalence of infection is much lower. The greatest impact of leptospirosis is for disease in humans, where it is manifested as a flu-like illness. It can be very debilitating, with frequent relapses.

Leptospirosis is usually diagnosed by serology which measures the level of antibody present in the blood. Bleeding 15–20 at-risk animals will give an indication of prevalence and whether the infection is recent. A second blood sample four to six weeks later will assist in the diagnosis. Laboratory examination of mastitic milk, aborted foetuses and dead calves will help confirm a diagnosis of leptospirosis. Regular vaccination of cattle is recommended, mainly to reduce the risk of human leptospirosis. Vaccination leads to a decrease in the shedding of bacteria. Oswin (2000), McGowan (2003) and Zelski (2007) provide further reading.

Trichomoniasis

Trichomoniasis is caused by the protozoa, *Trichomonas fetus*, which lives in the reproductive tract. Prevalence rates of 25% and 6% for bulls and cows respectively have been detected in extensive herds in northern Australia. The infection is less likely in intensive herds. The source of infection for bulls is an infected carrier female. There are no lesions of diagnostic significance in infected bulls and the organism does not affect either semen quality or sexual behaviour. Older bulls (four or more years) are more likely to become permanent carriers than younger bulls.

Infection in females is characterised primarily by early pregnancy loss and occasionally by abortion and pyometra (i.e. accumulation of pus in the uterus). Infection does not normally persist in non-pregnant females for more than a few months. In animals which conceive, the infection is sustained until abortion occurs; it may then be spontaneously eliminated within one to two weeks of abortion unless pyometra develops. Most cows that have calved normally are not infected.

In one well-controlled study in northern Australia (McGowan 1998), a trichomoniasis-infected herd had an 18% lower calving percentage than a similarly managed non-infected herd. In beef herds with short breeding seasons, trichomoniasis may result in a high percentage of non-pregnant cows. In herds with longer breeding seasons, the percentage of cows pregnant may be relatively high since a degree of immunity develops; however, an increased proportion of calves are born late.

Following development of immunity and elimination of infection, females are generally resistant to reinfection for ~20 months. There is no approved effective treatment or commercial vaccine available. The best strategy to minimise the impact of the disease is to cull infected bulls, non-pregnant females and females which fail to wean a calf. For the next breeding season, options include mating heifers to young virgin bulls or using artificial insemination. For further reading see Walker and McKinnon (2011).

Neosporosis

This disease is caused by the protozoan parasite, *Neospora caninum*. Cattle are an intermediate host and are most likely infected by eating oocysts (eggs) passed by domestic and wild dogs and dingoes. Dogs become infected following ingestion of meat and tissues containing infective cysts. Faecal contamination of pasture and prepared foodstuffs is the most likely source of initial infection in a herd but the main mode of transmission is vertical, from an infected female to her offspring during pregnancy. The disease has been considered the most important cause of infectious abortion in coastal NSW beef and dairy herds, with both sporadic and major outbreaks of abortion (Walker 2004). The prevalence of neosporosis in northern beef herds is high. A study (Kirkland *et al.* 2009) of 11 beef herds in Queensland found all were infected with neosporosis, with prevalences ranging from 4–25%. However, there was no firm evidence of reproductive loss associated with the disease except in one herd.

Abortions in heifers and cows range from three months gestation to term. Weak calves showing evidence of mild to severe paralysis have resulted from maternal *N. caninum* infection. Cattle which have aborted previously have a significantly increased chance of aborting again from this disease. The majority of calves infected during pregnancy are born normally and remain clinically normal throughout life, and thus can be selected as replacement breeding animals. There is no effective treatment or vaccine for neosporosis. For further reading see Walker (2004).

Bovine pestivirus or bovine viral diarrhoea virus

Bovine viral diarrhoea virus (BVDV) belongs to the genus *Pestivirus*, hence its common name pestivirus. It causes a variety of clinical entities including bovine respiratory disease (BRD) mainly in feedlot cattle (Chapter 11), reproductive wastage, mortality of young cattle and mucosal disease. It is widespread across Australia: ~60% of cattle have neutralising antibody to pestivirus and only 10% of herds are without serological evidence of previous infection. The virus is spread primarily by close contact. Infection of cattle should be considered in two distinct categories – pre-natal infection (from ovulation through to calving) and post-natal infection (from birth onwards). After birth, animals may be protected from infection either by colostral antibodies for up to five months or by immunity which develops subsequent to infection or vaccination. Immunity following natural infection is long-lasting, probably for the life of the animal.

There are two types of infection, transient or acute infection and persistent infection. Transient infection occurs over seven to 10 days and the clinical signs of a mild viraemia generally go unnoticed. Virus is shed in low concentrations and is not a major source of spread of the disease. If a susceptible (antibody-negative) female is infected during pregnancy, there are several reproductive outcomes of that pregnancy. Early in pregnancy there is fertilisation failure and embryonic mortality. When the foetus is infected between days 25–125 of gestation, the foetus' developing immune system recognises the virus as 'self'. If the foetus survives the infection to term, the resulting calf is infected for life, a so-called persistently infected (PI) animal. If the foetus is infected after about day 125 of gestation, there may be abortion or foetal mummification, or the foetus may be able to mount an immune response and will be born immune to BVDV. PI animals shed large amounts of virus and although they represent only ~1% of the herd they are the major source of spread of infection. About half of all PI cattle die within the first 12 months of life and about half of the survivors in the next 12 months, although some survive for many years. There are effective vaccines for BVDV and BRD (Chapter 13). Detailed information on the diagnosis and control of BVDV is available (Pfizer 2013).

Bovine ephemeral fever virus (three-day sickness virus)

Bovine ephemeral fever (BEF) is a viral disease of cattle primarily transmitted by mosquitoes and biting midges, especially sandflies. Spread of the disease depends on seasonal conditions, with rain and prevailing easterly and southerly winds necessary for the survival and dispersal of the insect vectors. It is normally a disease of the summer and early autumn. Many cattle are not infected until they are mature.

There is an initial acute stage with elevated body temperature, shivering, arched back and head down, followed by muscular stiffness and lameness with many heavier animals lying. Up to 10% of infected animals abort, usually between the second and seventh months of gestation. Infected bulls can be subfertile for several months because of elevated body temperature and its effect on spermatogenesis (Burgess and Chenoweth 1975). Most infected animals recover. About 1% of infected animals die, but this may be higher in extensive herds because of the difficulty of feeding and watering recumbent animals. Following infection, cattle are immune for at least two years.

Diagnosis of BEF is made on clinical signs and verified by detection of virus in the blood, in the acute stage of the disease. Alternatively, development of antibodies can be demonstrated with serial blood sampling. In regions where BEF occurs, vaccination of bulls is recommended and vaccination of replacement heifers should be considered.

Akabane virus

Akabane virus infection is the main cause of the congenital abnormalities, arthrogryposis (contracture of one or more limbs) and hydranencephaly (absence of cerebral hemispheres in the brain). The major vector is the biting midge *Culiciodes brevitarsis*, which feeds on cattle and breeds in dung. The range of *C. brevitarsis* is north of a line from the NSW south coast to the Pilbara in WA. Epizootics with substantial calf losses have been described in NSW at intervals of ~10–15 years (McGowan and Kirkland 2003).

In south-eastern Australia, virus transmission occurs from October to May and in northern Australia from May to October. Following an outbreak of Akabane virus infection there is sequentially an increase in abortions and stillbirths, then the birth of calves unable to stand (encephalopathy), then calves with varying degrees of arthrogryposis (one or more limbs affected, often associated with dystocia), then blind 'dummy' calves (hydranencephaly) and finally birth of 'dummy' calves unable to stand (microcephaly – small brain) (McGowan 1991). There is no commercially available vaccine.

Other infectious diseases causing reproductive losses

Disease from infection with the bacteria *Salmonella*, *Listeria monocytogenes* and *Escherichia coli* is usually associated with more intensive systems in southern Australia. These infections can cause abortion or death of young calves and are discussed in Chapter 13.

Strategies for controlling infectious causes of pre-natal and peri-natal losses

These are detailed in Cortese (2009) and Chapter 13. They involve four areas.

- Minimising the risk from introduced animals – purchased cattle or cattle returned from shows, agistment or neighbours represent a threat of introducing disease. The carrier of disease generally shows no clinical signs. Purchased animals should be tested for common pathogens such as campylobacteriosis, trichomoniasis, pestivirus and neosporosis. Introduced animals should be isolated for at least two weeks – the maximum range of the incubation period for most diseases. Isolation needs to be thorough – direct contact can still take place through a fence. The minimum buffer is 7 m to avoid aerosol contact and the quarantine area should be downwind of the prevailing wind direction.
- People and biosecurity – staff should be trained in disease recognition and proper use of waste management and equipment. Visitors should have limited access, particularly in intensive management systems. Visiting professionals and staff should minimise mechanical introduction by entering the property with clean boots, clothing, equipment and vehicles.
- Vaccination – no matter how good the biosecurity procedures, some diseases, particularly insect-transmitted disease such as BEF, will still be introduced. A comprehensive vaccination program, along with good nutrition, will limit the severity of disease. Vaccination programs in replacement stock have two aims. The first is to protect the animal against disease and

the second is to prepare the animal for entry into the breeding herd.

- Wildlife exposure – diseases such as leptospirosis and neosporosis have wildlife such as pigs, dogs and dingoes as part of their lifecycle. Ways to minimise exposure include eradication programs and preventing wildlife access to stored feed and water sources, although in many cases this is impossible.

Vaccination schedules for reproductive diseases

Vaccines should be given so that animals at risk of infection have time to develop adequate immunity before anticipated exposure to the organism. Vaccination of the cow will provide protection to the calf through passive immunity providing calves have adequate colostral intake; this immunity then lasts for five to six months. This immunity will gradually decline and young cattle will require vaccination for protection. The level and duration of protection is different in every vaccinated animal due to biological variability (Cortese 2006).

It is difficult to be prescriptive for vaccination protocols as programs will be dictated by local prevalence of diseases, the risk of infection, the price and effectiveness of the vaccine and stock handling schedules. Broad recommendations are presented in Table 14.2. These intervals can be modified under veterinary advice such that the pre-mating vaccinations can be given at time of pregnancy diagnosis to avoid handling cows with young calves.

In addition to the above vaccinations, tick fever vaccination of all weaners and of introduced bulls is recommended in endemic areas. It is also recommended that bulls be vaccinated against BEF but vaccination of commercial cows may not be warranted.

BULL BREEDING SOUNDNESS EXAMINATION

Definition of bull fertility

Fertility is used loosely to describe various reproductive traits or states. The Australian Cattle Veterinarians (ACV) has adopted this definition of fertility: 'an animal is fertile when it is able to reproduce prolifically'. There are four categories which describe the range of fertility states in bulls:

- fertile bulls can impregnate by natural service at least 60% and 90% of 50 cycling, disease-free females within three and nine weeks respectively;
- Subfertile bulls can achieve pregnancies by natural service but not at the same rate as fertile bulls. Subfertile bulls are also those that cannot achieve pregnancies by natural service but can produce viable semen for artificial breeding;
- infertile bulls temporarily cannot achieve pregnancies;
- sterile bulls permanently cannot achieve pregnancies.

Reasons for undertaking a bull breeding soundness examination

The main reason for conducting a bull breeding soundness examination (BBSE) is to describe whether a bull is 'fit for purpose' (Parkinson 2011), whether for single-sire or multiple-sire mating or for providing semen for artificial breeding. A BBSE is a relatively quick and economic procedure for screening bulls before sale or mating and is effective in identifying bulls that are subfertile, infertile or sterile. It is less effective in identifying the really highly fecund bulls ('super bulls').

Table 14.2: Vaccination programs for common reproductive diseases

	Age/time of vaccination	Pestivirus	Campylobacteriosis	Leptospirosis and clostridial diseases
Calves	6 wk			✓
	12 wk			✓
Heifers	6–8 wk pre-mating	✓[1]	✓	
	2–4 wk pre-mating	✓	✓	✓
	Pre-calving			✓
Cows	2–4 wk pre-mating	✓	✓	
	Pre-calving			✓
First season/new bulls	6–8 wk pre-mating	✓	✓	✓
	2–4 wk pre-mating	✓	✓	✓
Bulls	2–4 wk pre-mating	✓	✓	✓

1. Interval between the primary and booster dose can be extended to six months.
Source: Adapted from L. Taylor, Pfizer Animal Health.

A satisfactory BBSE is not a guarantee but rather an indication of reproductive performance. A satisfactory BBSE means that no abnormality has been found that will interfere with a bull's reproductive efficiency. Overall judgment of the bull being fertile or not is inappropriate because other factors such as female reproductive status, accidental injury, presence of endemic disease and bull paddock behaviour may have a large contribution to calf output in a particular situation. There is sufficient information under Australian conditions to indicate that the correct application of BBSE principles will result in overall improvement in herd reproductive rates.

Components of a BBSE

The BBSE aims to establish a baseline for a range of objectively measured traits above which bulls can be regarded as having a high probability of being potentially fertile. Below these thresholds, bulls may be subfertile or infertile. The BBSE needs to be comprehensive as it provides information for the vendor, purchaser, breed society, beef improvement organisations, show committees and insurance companies. The ACV manual (Entwistle and Fordyce 2003) specifies the correct procedures for conducting a BBSE.

There are five key components to a BBSE (Entwistle and Fordyce 2003):

- a physical examination to describe and assess the health of the bull (Physical);
- an examination of the reproductive organs including the scrotum and scrotal contents (Scrotum), penis, prepuce and internal reproductive tract;
- a serving assessment to evaluate libido and mating ability (Serving);
- collection, assessment and description of a semen sample (Semen);
- an evaluation of sperm morphology to assess the proportion of normal and abnormal sperm (Morphology).

Additional information that can be provided includes vaccination history and diagnostic tests for diseases such as BVDV, campylobacteriosis, trichomoniasis, Johne's disease and tests for genetic abnormalities such as mannosidosis and Pompes disease. Bull Reporter, a recording and reporting system based on the standards of the ACV manual, groups traits into five summary categories: Scrotum, Physical, Crush-side Semen, Sperm Morphology and Serving (Fordyce *et al.* 2006).

Not all components of a BBSE are necessarily assessed; testing is based on the intended use of the bull. Bulls for single-sire or multiple-sire mating with a high female:bull ratio should have all components of a BBSE assessed. Bulls for multiple-sire mating in extensive areas should have, as a minimum, an assessment of Physical, Scrotum and Semen. Regardless of the intended use, the more components of a BBSE that are included in the examination the greater the chance of a subfertile or infertile bull being detected.

Limitations of a BBSE

A BBSE indicates likely reproductive status at the date of evaluation. Subsequent events such as injury or inappropriate mixing of new and established bulls in a mating group may affect bull fertility. The ACV recommends that a BBSE using ACV standards conducted within 70 days of a sale may be used as an indicator of bull fertility at time of sale. That a bull passes a BBSE pre-sale does not indicate that it will pass in the immediate post-sale period as relocation may have a significant effect on semen traits. Fat bulls should be re-examined after acclimatisation. This period is highly variable and may take two to four months to restore normal testicular function.

Physical examination

The examination should be thorough enough to describe the bull unambiguously and to state that the bull is in good health. With any abnormalities, the examination should provide a diagnosis and prognosis. With groups of bulls, a detailed history may be necessary only for bulls with significant physical or physiological abnormalities. Assessment of cardinal signs such as rectal temperature and heart rate are appropriate only for insurance purposes or investigations of suspected subfertility. Recording body condition and liveweight provides an indication of previous nutrition, which has implications for the interpretation of scrotal circumference and testicular function. The examination should record vaccination history.

An examination of the musculoskeletal system involves the head, body, legs, feet and gait. The animal should be examined systematically by hand and eye from the head, along the neck and shoulders, down the forelimbs, along the thorax and abdomen to the lumbar region, over the hindquarters and down the hind legs It is important to differentiate between an abnormality as opposed to a variation of the norm, particularly with leg and feet symmetry. In general, a structural fault is considered important when it is interfering with reproductive function.

Feet conditions to note are angulation of the pastern and hoof size and symmetry. Angulation of the pastern is normal, while excessively straight or sloping pasterns could cause lameness. Claws of the hoof should be of equal size and symmetry. Claw defects may be associated with undesirable limb conformation or may reflect high-energy diets, mineral deficiencies or lack of exercise. Common foreleg faults include bow legs and knock knees while common back leg faults include sickle hocks, cow hocks and straight legs (posty legs), with the latter being of most concern. Limb defects may be primary (thus likely to have some genetic predisposition) or acquired, such as interdigital fibroma as a sequel to repeated interdigital dermatitis. Limb conformation defects are sometimes regarded as blemishes but may lead to later-in-life dysfunction. Mild swelling of the joints, particularly the hock, is often associated with high-energy diets but it also can occur secondary to fighting.

While the greater part of the physical examination is done in the crush, examination of the bull's conformation and gait is best done with the bull standing in a holding yard before entry into the crush and during a serving assessment. It can also be done on exit from the crush, although such procedures as electroejaculation may cause temporary lameness and stiff gait. The placement of feet (tracking) should be observed while the bull is both walking and trotting. The gait should be smooth with no head or hip bobbing; the rear foot should land near the front foot. Overstepping or understepping of the feet may be associated with recurring lameness or problems when serving. Joint lesions should be taken into consideration as a contributory cause of reproductive failure in bulls even without symptoms of lameness (Persson *et al.* 2007).

Examination of the scrotum and its contents

The scrotal sac can be examined from behind with the bull restrained in a squeeze crush with a half gate. Most bulls tolerate the procedure well. Gentle pressure may be needed to draw the testicles into the scrotal sac. The sequence should be to observe first, then palpate, then measure scrotal circumference. The scrotum and testicles should be palpated carefully using the thumb and fingers of both hands, at the same time methodically examining from the neck of the scrotum containing the spermatic cord and blood vessels down to the tail of the epididymis. The cardinal rule in examination of the scrotal sac is that left should equal right in symmetry. The scrotal neck may be enlarged due to fat deposition or varicoeles.

The scrotal skin should be thin, cool and pliable without any evidence of significant skin lesions. The testicles should be freely moveable in the scrotal sac. The testicles of *Bos indicus* and *Bos indicus*-derived bulls are usually longer and narrower than those of *Bos taurus* bulls. Many of the variations in scrotal shape, such as lateral rotation and distinct cleavage, are blemishes of no functional importance. Both unilateral and bilateral hypoplasia (smaller than normal testicles) are heritable and associated with low daily sperm production, poor motility and elevated levels of abnormal sperm. Testicles held high because of a short scrotal neck or a scrotal tie (a fold of skin on the scrotum) may have poor thermoregulation and thus poor semen quality. Pendulous scrotums can lead to mechanical injuries.

Testicular tone is a subjective assessment of testicular tissue and provides a guide to testicular health. Tone is measured with the fingers and thumb on the anterior and posterior surfaces of the testicle, which is steadied at the upper pole by the other hand. Tone has two components: firmness, which is the degree of compression of the testicle using firm pressure, and resilience, which is the degree of springiness or return to shape of the testicle. Good testicular tone is firm and resilient (springy). Fibrosed testicles, which are associated with increased age and trauma, are very firm with low resilience while degenerative or hypoplastic testicles are soft with low resilience. The scores of both firmness and resilience are combined into a 1–5 scale for testicular tone where 1 is very soft and 5 is very hard. Normal testicles score either 3 or 4. Testicular tone in *Bos indicus* bulls is not correlated strongly with scrotal circumference (McGowan *et al.* 2002), seminal traits (Fitzpatrick *et al.* 2002) or calf output (Holroyd *et al.* 2002). The value of measuring testicular tone is in determining gross changes in tone (very soft or very hard) rather than detecting subtle differences.

Scrotal circumference measurement and its interpretation

Scrotal circumference, often called scrotal size, provides a good estimation of daily sperm production by the bull. Scrotal circumference is moderately to highly heritable. There is a good correlation between circumference and testicular weight and daily sperm production (Wildeus 1993), but not with calf output (Holroyd *et al.* 2002).

Scrotal circumference should be measured when both testicles are completely within the scrotum and are side by side (Fig. 14.6). The thumb and finger of one hand is placed on the neck of the scrotum so as to cradle the testicles and hold them firmly. If the testicles are 'grasped' it may inflate the measurement. A scrotal tape is formed into a loop and slipped upward around the scrotum then

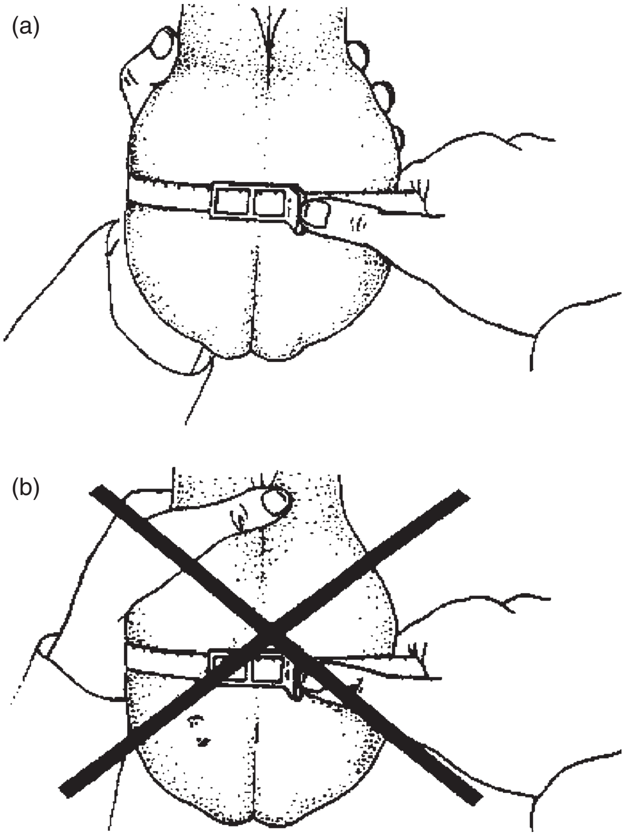


Figure 14.6: (a) Correct method for measuring scrotal circumference. (b) Incorrect handling. Source: Ott (1986).

tightened snugly around the greatest diameter. The tension of the tape should be sufficient to cause a slight indentation in the scrotum. A springload scrotal tape allows a constant tension to be applied and thus provides consistency between measurers.

Age, breed and plane of nutrition are important factors influencing testicular size and thus scrotal circumference. At similar weights and ages, young *Bos indicus* bulls tend to have smaller scrotal circumferences than *Bos taurus* bulls. Scrotal circumference can increase under good nutritional conditions and decrease as nutrition and liveweight decline. This lability of testicular tissue is particularly evident in bulls after the seasonal break in extensive herds in northern Australia.

Scrotal circumference is an important measurement but selection based on a large scrotal circumference should be done only cautiously. While there are good genetic correlations between scrotal circumference and female fertility traits such as reduced age of puberty (Corbet *et al.* 2011), scrotal circumference is not a good indicator of calf output (Holroyd *et al.* 2002). Rather, bulls should be assessed on the basis of reaching a minimum or threshold value that can be influenced by breed and environment (Table 14.3).

Table 14.3: Guidelines for threshold values for scrotal circumference

Age	Bulls reared on a moderate to high plane of nutrition	Bulls reared on a low plane of nutrition
12–15 months	30 cm	24 cm
18 months	32 cm	28 cm
2+ years	34 cm	30 cm

Source: Entwistle and Fordyce (2003).

The highly significant and positive relationship between scrotal circumference and liveweight (age is of less importance) for *Bos indicus* and *Bos indicus*-derived breeds is demonstrated in Fig. 14.7 (Muller *et al.* 2010). Breed differences in testicular development are small although Belmont Red and tropical composite bulls mature at slightly earlier age/weight than the other breeds. While a similar study has not been done in *Bos taurus* bulls, the general principles should apply. Using the values in Fig. 14.7, an estimation of whether the scrotal circumference of a bull is within normal range can be made regardless of previous nutrition and its effect on growth and body condition.

Examination of the prepuce, sheath, umbilicus and penis

The sheath is the external hair-covered appendage which contains the penis, the prepuce which is the mucosal lining within the sheath, and the umbilicus which contains the remnants of the umbilical blood vessels and

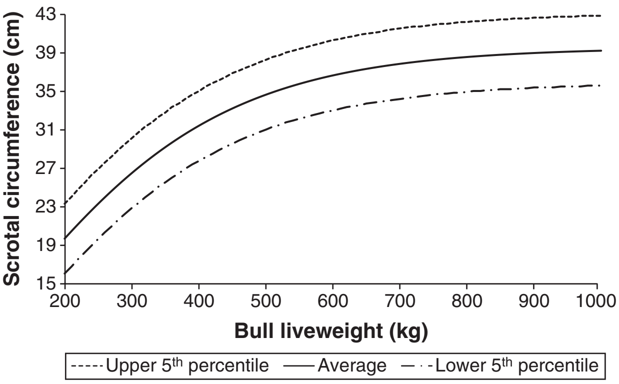


Figure 14.7: Scrotal circumference measurement for tropically adapted bulls according to their bodyweight. Source: Muller *et al.* (2010).

the external umbilical scar or navel. For simplicity, the whole structure will be referred to as the sheath.

The sheath can be observed at the same time as observing conformation. The sheath and penis can be palpated with the bull restrained in a crush, but many bulls will not allow proper relaxation of the sheath. However, most bulls eventually do, particularly after semen collection. Eversion of the prepuce exposing the mucous lining is quite common in *Bos indicus* breeds but persistent eversion of more than 10 cm of prepuce is undesirable as it may predispose to preputial injury and prolapse. Sheaths are scored on a scale of 1–5 where 1 is very tight and the sheath is close to the abdominal wall, 3 is moderate with the sheath hanging at about a 45° angle and a depth less than 20 cm and 5 is very pendulous with the sheath hanging up to a 90° angle to the body (Entwistle and Fordyce 2003). Desirable sheath scores for *Bos indicus* bulls or *Bos indicus*-derived bulls should be 4 or less while those of *Bos taurus* should be 2 or 1. Pendulous sheath shape can be associated with trauma, with resulting prolapse of the prepuce. The diameter of the sheath including the penis is sometimes referred to as the cord. There is little evidence that 'heaviness' or size of the cord in Santa Gertrudis bulls has any significant influence on bull performance or that cord size is a reflection of the resting position of the penis within the sheath (J.D. Bertram, pers. comm.).

The erect penis is best observed during service. Lesions such as penile haematomas (broken penis) may be missed on observation but readily detected on palpation. The penis can be protruded in most bulls if an assistant passes a gloved, lubricated hand into the rectum. Gentle stimulation with the fingers of the pelvic portion of the urethra will help with protrusion and often cause a partial erection. Protrusion of the penis will detect most lesions except for spiral deviations that can only be detected during observation of service from the right side.

Common abnormalities of the penis are fibropapilloma (warts), particularly with *Bos taurus*, trauma of the free end of the penis and associated preputial damage, and penile deviations. The main penile deviation is premature spiral deviation of the penis (PSDP, or corkscrew penis) with the spiral configuration always to the right side. While mounting, PSPD may occur within the sheath or when in contact with the female and intromission (penetration of the vagina) does not occur. The symptoms may develop from mild (deviation in less than 25% of serves) to moderate (30–70%) and severe (75% or more serves). Spiral deviation can occasionally occur during electroejaculation but is not considered to be a PSPD. PSPD causes moderate to marked reductions in pregnancy rates, particularly in bulls mated as single-sires (Blockey and Taylor 1984).

Examination of the internal reproductive organs

The accessory sex glands, seminal vesicles, ampullae and bulbourethral glands can be palpated per rectum, noting size, symmetry and consistency. The most common abnormalities involve the seminal vesicles and range from enlargement to inflammation or congenital defects such as segmental aplasia. The prevalence of seminal vesiculitis (an acute or chronic inflammatory process) may be as high as 10% (Bagshaw and Ladds 1974; Cavalieri and Van Camp 1997) with some cases resolving without treatment. Close confinement, high-energy diets and age are factors associated with a higher prevalence. The condition is more commonly seen in young peri-pubertal bulls and bulls over nine years (Cavalieri and Van Camp 1997).

Semen collection and assessment

Semen examination is important to determine the breeding potential of the male or the batch of semen in question. There are limitations to the accuracy of evaluation of semen quality, both inherent and iatrogenic. The inherent limitation is that predicted performance is based on data reflecting previous (up to several months earlier) spermatogenic history. Iatrogenic limitations are from methods used to collect, handle and examine semen and by interpretation of the results (Chenoweth 2009).

Evaluation of semen quality is based on assessments of motility, viability, density and morphology. The correlation between any one of these traits and mating outcome is not high and estimates of semen quality can, at best, be considered a guide to the likely fertility of the male when the semen sample is taken. There are numerous instances of samples of equally high-quality semen taken from different males, which produced vastly different results when used in artificial insemination programs (Entwistle 1978). Given the limitations of semen evaluation, collection of a representative sample of semen and its visual and microscopic assessment against a set of minimum threshold standards are integral parts of a BBSE.

Methods of semen collection

Semen collection by artificial vagina (AV). This is the method of choice as it not only enables collection of an ejaculate but allows an assessment of libido and mating ability. It is used widely in artificial breeding centres. It requires bulls to be trained; it needs teaser animals for mounting and staff with good stock handling skills.

Semen collection by electroejaculation (EE). In most field situations semen collection is usually possible only using EE or massage. EE involves the insertion of a probe into the rectum and the application of low-level electrical stimulation of the nerves responsible for emission and ejaculation. The stimulus is increased in a rhythmic and stepwise process until ejaculation is completed. An erection of the penis may occur and most bulls will provide a semen sample with relatively little stress on the bull (Whitlock *et al.* 2012).

Semen collection by rectal massage of the ampullae. This involves gentle massage and stroking of the ampullae by a gloved hand inserted into the rectum. A rhythmic motion is used, avoiding the lobulated seminal vesicles; stimulation of these can produce large amounts of seminal plasma, particularly in *Bos indicus* bulls. As emission and ejaculation commences, strong pulsations of the pelvic urethra will occur. Most bulls will partly extrude the penis and an assistant can gently grasp the penis and extrude it for closer examination. Generally an ejaculate can be obtained within two to three minutes although the volume will generally be less than with EE.

Collection and handling of semen samples

The semen sample should be free of contaminants such as mud or dust and be collected into a clean dry rubber or plastic funnel attached to a collection tube. Collecting too much seminal fluid dilutes the sample. In cold conditions, the funnel and collection tubes should be pre-warmed to ~37°C to avoid cold shock. The ejaculate should not be exposed to sunlight.

Crush-side examination of semen

Semen should be visually examined immediately after collection to determine volume, density and colour. A good sample of semen is greyish white to pale cream in colour. Discolouration can be from urine or blood. Clumps of flocculent material are indicative of pus. A visual estimation of density can provide an estimation of concentration, with values ranging from 1 (clear to cloudy ejaculate with approximately <200 M sperm/mL) to 5 (thick creamy ejaculate of >1500 M sperm/mL) (Entwistle 1978). In ejaculates for freezing, concentration should be measured using a calibrated spectrophotometer or a haemocytometer to ensure appropriate dilution with diluent for correct sperm numbers per straw.

Motility is measured as both mass activity and progressive motility. Viewing a drop of semen on a warmed slide at 40–100 times magnification allows an estimation of mass activity (wave motion, gross motility). It is scored on a scale of 1–5 where 1 is no swirl, generalised oscillation of individual sperm only, 3 is slow distinct swirl and 5 is fast distinct swirl with continuous dark waves. Mass activity is a function of both sperm concentration and progressive motility and provides a guide to sperm motility, but there is not a good relationship with mating outcome (Holroyd *et al.* 2002). Progressive motility (more commonly called motility) is an assessment of progressive forward motility of individual sperm under a coverslip at a magnification of 400 times; it is scored as percentage progressively motile sperm. The acceptable minimum threshold for bulls used for natural mating is 30% motility, while 60% is the minimum threshold for semen to be frozen for artificial insemination. Precision instruments such as computer-assisted sperm analysis devices provide more precise estimates of motility but their cost and lack of portability mean that they are generally confined to laboratory assessments.

Morphological examination of semen

Morphology (the shape of sperm) provides information on testicular and epididymal function. Sperm lose their fertilising capacity before losing their motility; sperm with morphological abnormalities can still have good motility. An understanding of the various morphological abnormalities allows a diagnosis of causes of subfertility and infertility and a prognosis of future fertility.

Assessment of morphology is usually done at a laboratory as it requires phase contrast microscopy at 1000 times magnification, but it can be done in the field with the appropriate equipment and training. The ACV has a scheme for morphologists to ensure uniformity of assessment. Either stained slides or, more commonly, a subsample of semen (0.02–0.05 mL) in a fixative is submitted to a laboratory. Usually 100 individual sperm are examined and a morphology report provides the percentage of normal and abnormal sperm. There is good evidence that the percentage of normal sperm in an ejaculate is related to calf output of individual bulls when multiple-sire mated (Holroyd *et al.* 2002).

The tolerance levels of particular abnormalities for a satisfactory BBSE are based on whether the abnormality is compensable or uncompensable (Saacke *et al.* 1994). Compensable abnormalities such as tail defects preclude sperm fertilising as they cannot reach the ova. Increasing the number of sperm in the ejaculate may compensate for this abnormality. An uncompensable abnormality, such as sperm with vacuoles in the head, can reach the ovum.

It may fertilise the ovum but it results in abnormal development and early embryonic mortality; increasing the number of sperm in an ejaculate or insemination will not compensate for these types of abnormality. A compilation of importance of sperm abnormalities are provided by Barth and Oko (1989) and Perry *et al.* (2002). The ACV classifies abnormalities and their percentage tolerance levels into seven groups (Entwistle and Fordyce 2003):

- proximal cytoplasmic droplets – uncompensable ≤20%;
- mid-piece abnormalities – compensable ≤30%;
- tail abnormalities and loose heads – compensable ≤30%;
- pyriform heads – uncompensable ≤20%;
- knobbed acrosomes – compensable ≤30%;
- vacuoles and teratoids – uncompensable ≤20%;
- swollen acrosomes – compensable ≤30%.

The ACV recommends that 70% normal sperm be the threshold for bulls for single-sire matings or that the ejaculate is suitable for freezing (given that the ejaculate passes motility and concentration requirements). Bulls with 50–69% normal sperm still have a high probability of being fertile under natural mating but are risks when mated as single-sires or under high mating loads. Their semen may not be suitable for freezing. Bulls with <50% normal sperm are capable of siring calves but will take considerably longer to impregnate females (Holroyd *et al.* 2005).

High levels of abnormalities can be innate or transient and are indicative of degenerative changes of the testis and epididymis due to factors such as immaturity, heat stress, overfeeding and disease such as ephemeral fever. Approximately 61 days are required for spermatogenesis plus another 10–12 days for passage of the sperm through the epididymal tract. This provides some indication of re-test intervals and likely recovery time depending on the abnormalities.

Serving assessment tests

Mating behaviour in bulls is a combination of libido (sexual motivation) and ability to serve. Their importance for reproductive performance of a bull has been reviewed by Blockey (1976), Chenoweth *et al.* (2002) and Petherick (2005). The mating behaviour of bulls can be assessed in a serving capacity test or a serving assessment or serving ability test. These measurements require considerable skills and experience to conduct and interpret. Techniques have been developed for *Bos taurus* (Blockey 1989) and *Bos indicus* (Bertram *et al.* 2002) breeds.

A serving capacity test measures the number of serves of restrained females by a bull during a set time period following adequate sexual stimulation. This period is usually 10 min for *Bos taurus* bulls and 20 min in *Bos indicus* bulls. Bulls can be assessed simultaneously in groups according to age, social relationships and number of restrained females. Serving capacity testing can rank bulls so that the number of serves determines the intended use of the bull. Higher numbers of serves are required for bulls mated as single sires for a short period but a lower number is acceptable for bulls multiple-sire mated for several months. An increase in number of serves in *Bos taurus* bulls resulted in a corresponding increase in conception rates (Blockey 1989). Serving capacity is highly heritable (0.67; Blockey et al. 1981) and thus a useful tool for selection in *Bos taurus* herds.

A serving ability test primarily determines if a bull can serve normally rather than determining the total number of serves (serving capacity). It is used mainly but not solely with *Bos indicus* breeds because bulls may not be handled as frequently. Detection of abnormalities such as PSPD requires observing bulls several times attempting to serve as affected bulls may initially serve normally, especially in the onset of this condition. Various measures of sexual behaviour (e.g. interest, mounts or serves) were unable to consistently predict calf output of *Bos indicus* bulls in multiple-sire matings (Bertram *et al.* 2002).

The use of two terms, 'serving capacity' and 'serving ability', led to confusion so the ACV has chosen to use 'serving assessment' as part of the BBSE procedure. The success of serving assessment tests is highly dependent on skilled and experienced operators, the availability of good yards and suitable test females. Both types of tests can be conducted using either restrained or unrestrained, oestrous or non-oestrous females with the use of restrained females providing a better evaluation of the bull. The conduct of the tests is described in Entwistle and Fordyce (2003) but the basic premise is that the greatest single stimulus for a bull to attempt to mount is the immobile rear end of a female or something similar in appearance (Chenoweth *et al.* 2002).

Under the ACV guidelines, to be considered sound for breeding using the serving assessment, bulls must have:

- at least one serve within 10 min or 20 min for *Bos taurus* bulls and *Bos indicus*-content bulls respectively;
- a normal penis which can be observed during the test;
- a normal musculoskeletal system with no other attributes preventing the bull mating naturally.

Testing for infectious disease and carrier status for genetic diseases

Testing for transmissible diseases, especially venereal and congenital diseases, or for genetic defects is not conducted routinely as part of a BBSE unless specifically requested. The exceptions are bulls purchased as semen donors, frozen semen being imported or exported and where national or international disease-free certification may be required. Unless testing is indicated or reported, the BBSE report does not indicate freedom from carrier status for infectious or genetic diseases.

MANAGING BULLS FROM WEANING TO MATING

Managing groups of young bulls

Weaning bull calves at six to eight months or older can cause problems within the breeder herd. These unweaned bull calves may become sexually active and attempt to serve cycling cows, leading to injuries, unwanted pregnancies and rectal prolapses to the bull calves. Running groups of weaned bulls together is efficient for feeding and vaccination programs and parasite control but the optimal size of bull groups has not been quantified. Bull breeders would suggest that groups of 15–30 are relatively easy to manage. Providing there is not a large weight range, there are few problems with bullying, trauma or homosexual activity if running large groups (>400) of *Bos indicus* bulls either in feedlots or in the paddock up to two years of age. Sound fencing, in most cases, will keep animals confined. Similarly, groups of 50 or more *Bos taurus* bulls can be feedlotted for 70 days with few agonistic problems between bulls (R Holmes, pers. comm.).

Male sexual behaviour appears not to be affected if bulls have limited contact with other bulls or females during rearing (Lane *et al.* 1983). There have been reports that rearing bull calves without contact with females resulted in bulls in later life preferring to mount bulls rather than cows (Sambraus 1980). For bulls to perform well in serving assessment tests, they benefit from sexual experience. Young bulls learn the correct mount orientation through mounting experience (Silver and Price 1986). Libido scores and number of services increased when two-year-old Santa Gertrudis bulls were given sexual experience before the test (Bertram *et al.* 2002).

Puberty

Although commonly perceived as a set point in time, puberty in the bull is a continuous and dynamic process, commencing before birth, mediated through the hypothalamic-pituitary-axis, and influenced by a wide range of genetic and non-genetic factors (Entwistle 2002). Functional competence of all components of the male tract is not achieved simultaneously. The capacity for erection often precedes the appearance of sperm in the ejaculate by some months. Thus, various definitions of onset of puberty have been used. Some have been based on ejaculate characteristics where the standard of Wolf *et al.* (1965) is generally used, i.e. an ejaculate containing 50 $\times 10^6$ total sperm with at least 10% progressive motility. More relevant is the measurement of testicular size as a measure of puberty. Post-natal testicular development increases rapidly at ~14–15 weeks in *Bos taurus* (Amann 1983) and slightly later in *Bos indicus* (Igboeli and Rakha 1971). These changes are associated with a marked increase in testicular size until ~20–26 months of age, when testicular growth tends to plateau. In *Bos taurus* bulls pre-pubertal testicular growth is approximately linear (Coulter and Foote 1976) but in *Bos indicus* it is frequently non-linear (Tegegne *et al.* 1992) though this is probably not a reflection of genotype *per se* but rather a genotype *x* environment effect. At puberty, all components of the male reproductive system have reached a sufficiently advanced stage of development for the system as a whole to be functionally capable of impregnating females (Entwistle 2002).

Because of the different environments, nutritional pathways, breeds and methods of measuring puberty, there are large differences reported in the age at puberty of cattle (Table 14.4). As a general rule, puberty is attained when scrotal circumference reaches 26–28 cm. *Bos indicus* breeds tend to reach puberty later and have a smaller scrotal circumference at puberty than *Bos taurus* breeds (Entwistle 2002).

These studies were all done with animals grazing pasture. There is a dearth of reported information on puberty of bulls fed high-energy diets, as occurs in many stud operations. Undoubtedly, under these circumstances, bulls would reach puberty at a younger age although possibly at heavier weights.

Sexual maturity

After reaching puberty, bulls proceed through a period of sexual maturation. There is a continuing increase in scrotal circumference and changes in ejaculate characteristics. Sperm concentration and proportion of normal sperm increase but there is a decrease in proximal droplets (Barth and Oko 1989). Sexual behaviour changes as number and intensity of displays such as seeking, mounting and serving increase. By two years of age, the testicles of

Table 14.4: Estimates of age, weight and scrotal circumference at puberty of various breeds of bulls

Breed	Age (months)	Average liveweight (kg)	Scrotal circumference (cm)	Source
Hereford	10.9	261	27.94	Lunstra (1982)
Angus	9.6	273	28.7	
Red Poll	9.4	258	27.4	
Bos indicus cross	18.5	254	24.4	Wildeus *et al.* (1984)
Brahman	22.6	363	28.3	Perry *et al.* (1990b)
Belmont Red	21.3	341	30.3	
Shorthorn × Hereford	24.9	311	29.0	
Angus	13.8	307	29.8	Chase *et al.* (1997)
Brahman	16.6	411	29.6	
Hereford	13.6	318	28.7	
Senepol	13.9	370	29.9	
Brahman	17.4	340	28.0	Holroyd *et al.* (2005)
Belmont Red	15.4	330	30.0	
Angus and Angus × Charolais	10.4			Barth *et al.* (2008)
Brahman	18.5			Fortes *et al.* (2012)

bulls reared on a moderate to high plane of nutrition will have reached 90% of their mature size. If a bull has not achieved anticipated testicular size by then, there is a low probability that significant additional size will occur.

The age of attainment of sexual maturity as assessed by semen characteristics varies both within and between breeds. Bertram *et al.* (2000b) considered that sexual maturity for Belmont Red bulls was 14–17 months, as most bulls in the study in south-east Queensland had reached 70% normal sperm in an ejaculate and had one serve by this time. The same authors reported that most Droughtmaster bulls had reached 70% normal sperm in an ejaculate by 18 months. For Brahman bulls, sexual maturity is ~20–21 months as most bulls had reached 70% normal spermatozoa (R.G. Holroyd and V.J. Doogan, unpublished). Sexual maturity in *Bos taurus* is at an earlier age than in *Bos indicus*. In a Canadian study, the percentages of *Bos taurus* bulls with mature spermiograms at 11, 12, 13, 14 and 15 months of age were 20%, 30%, 51%, 52% and 61% respectively (Arteaga *et al.* 2001). Persson and Soderquist (2005) found that 48% of yearling *Bos taurus* bulls fed to grow at 1.5 kg/day from weaning at six months had mature spermiograms by 12 months of age.

Effect of nutrition on growth and reproductive development

Nutritional restrictions

Testicular tissue is nutritionally labile, thus scrotal size and hence sperm production capacity can increase and decrease depending on the plane of nutrition. Dietary restriction is usually associated with bulls reared on pasture. Undernutrition in the pre-pubertal period will reduce liveweight and testicular growth, thus delaying puberty in both *Bos taurus* (Van Demark and Mauger 1964) and *Bos indicus* bulls (Rekwot *et al.* 1987; Nolan *et al.* 1990). Because of marked seasonal variation in rainfall in northern Australia, there can be significant between-year variations in scrotal circumference, with group averages ranging from 23–28 cm at 18 months (Entwistle and Holroyd 1993) and 24–31 cm at 24 months of age (Fordyce *et al.* 1996b). These variations in scrotal circumference are generally a direct reflection of the degree of nutritional stress during the first dry season after weaning (Entwistle and Holroyd 1993).

Supplementing bulls can increase testicular size (Lindsay *et al.* 1982; Fordyce *et al.* 1996b). It is unclear if nutritional effects on pre-pubertal testicular development reflect either protein or energy deficits. On poor-quality pasture, protein and then energy are limiting and though responses to protein supplements may occur, these are more likely from stimulation of dry matter intake and hence energy intake rather than specific protein effects *per se*. This is supported by work with *Bos indicus* bulls in Africa, where restricting crude protein in isocaloric diets produced testicular changes similar to restricting energy in isonitrogeneous diets (Rekwot *et al.* 1988).

Bulls can lose or gain weight over the mating period depending on nutritional conditions, but this does not adversely affect calf output (Fordyce *et al.* 2002). At the transition from the dry to the wet season in extensive conditions, there are often marked and abrupt increases in both liveweight and scrotal circumference. The magnitude of this change is greater in younger than older bulls and suggests that nutritional supplementation during the dry season may arrest the normal decline in scrotal circumference (Entwistle and Holroyd 1983). Three-year-old Brahman cross bulls on poor-quality diets for six weeks lost 41 kg in liveweight and 1.5 cm in scrotal circumference (Ndama *et al.* 1983), with a corresponding reduction in sperm production. In summary, reproductive activity in the bull continues in spite of greatly reduced body fat or liveweight. While testicular size and sperm output decrease, sperm production (an obligatory function) continues, albeit at a reduced rate. Although libido is sometimes depressed when nutritional stresses are extremely severe, few underfed bulls cease mating activity entirely, though fertility may be impaired due to increased proportions of abnormal sperm in the ejaculate associated with testicular degeneration (Entwistle and Holroyd 1993).

High-energy diets

High-energy diets have been associated with impairment of fertility in bulls although the evidence is not clear-cut. The severity of the problem has to be assessed in view of the dietary level. Feeding high-energy diets from weaning to 24 months of age to Angus and Hereford bulls resulted in reductions of epididymal sperm reserves, semen motility and percent normal sperm. While there was an increase in scrotal circumference, there was no increase in paired testis weight, suggesting increased deposition of fat within the scrotum (Coulter and Kozub 1984). This may affect scrotal thermoregulation by reducing heat transfer from the scrotal neck and thereby increasing the temperature of the testes and scrotum, resulting in testicular degeneration (Coulter *et al.* 1997). Other studies found that feeding high-energy diets to weaner Hereford and Simmental bulls for 200 days had no effect on semen characteristics or serving capacity as yearlings (Pruitt and Corah 1985). Supplementing yearling Brahman bulls with commercial pellets (CP 15%, ME 10.4 MJ/kg, ~6 kg/day) increased liveweight by 150 kg and scrotal circumference by 4 cm over five months but there was no significant effect on semen quality (Holroyd *et al.* 2005).

The effect of pre-pubertal nutrition on subsequent libido is also not clear-cut. Plane of nutrition did not affect libido in either yearling Africander bulls (Maree *et al.* 1989) or *Bos taurus* bulls (Mwansa and Makarechian 1991). There was a breed–nutrition interaction effect: libido scores for Angus bulls were independent of nutrient intake while libido scores were lower in low-fed than in high-fed Senepol bulls (Chase *et al.* 1990).

Bulls fed high-energy diets may be predisposed to musculoskeletal disorders such as osteochondrosis dessicans (OCD) and laminitis (Greenough and Gacek 1987; Holroyd *et al.* 2005), which may reduce the bull's reproductive life. There was a very high incidence of OCD lesions in hind limb joints of yearling bulls in Sweden fed *ad libitum* high-energy diets for five months (Dutra *et al.* 1999).

While bulls are purchased with a heavy emphasis on high liveweight, good body condition and conformation rather than estimated breeding values, energy diets will continue to be used as part of the preparation for sale. There is a need to balance preparing bulls for sale so that a seller is not commercially disadvantaged, with excessive feeding which can compromise fertility. The effects of high-energy diets on semen quality may be transitory (Christmas 2001) but some bulls may never regain full fertility (Entwistle and Holroyd 1993).

Selection of bulls as weaners or yearlings

This should be based on birth, growth, reproductive and temperament traits and on genetic merit supported by visual assessment (Chapter 17). If possible, select 25–50% more animals than anticipated for sale or for mating. This allows some latitude for culling at a later age on traits such as growth and carcass.

Weaner bulls should have two normal testicles; cryptorchids and bulls with unilateral and bilateral hypoplastic (smaller than normal) testicles should not be selected. The latter category may be hard to identify as scrotal circumference, particularly in *Bos indicus* genotypes, tends to be in the range of 18–22 cm in bulls of 10–12 months of age. Scrotal circumference and sheath score are highly correlated and repeatable between the ages of 10–28 months (Holroyd *et al.* 2005), suggesting that it is possible to select or at least screen bulls at an early age for these traits. Care should be taken in comparing young bulls from dams of different ages as those born to young dams (<less than five years) and those born later in the calving season have a smaller scrotal circumference at two years of age than those born earlier from older dams (Fordyce *et al.* 1996b).

Selecting young bulls on semen traits early in life is not recommended as they are poorly related to later-in-life values. As bulls undergo sexual maturation, there are increases in normal sperm and a decrease particularly in head abnormalities and protoplasmic droplets (Lunstra and Echternkamp 1982). Percent normal sperm was poorly repeatable in bulls that were undergoing sexual maturation (12–21 months of age) but once bulls had reached sexual maturity repeatabilities of percent normal sperm were at least moderate, ranging from 0.41–0.78 (Holroyd *et al*. 2007).

There is no strong evidence that reproductive behaviour early in life reflects that in later life (D'Occhio and Kinder 1993). Serving tests are managerially easier to conduct with yearling bulls than older bulls as there is less disruption to the testing process through less overt aggression between bulls (Blockey 1979). In Hereford bulls, some animals that had low libido at 12 months of age showed satisfactory libido when tested at 18–24 months of age (Price and Wallach 1991). Libido score increased in older bulls compared with yearling bulls (Coulter and Kozub 1989; Perry *et al.* 1990a). Yearling bulls produced more interest displays and mounts than serves compared with older bulls in serving assessment tests (Bertram *et al.* 2002), suggesting that older bulls become more 'efficient' in serving assessment tests by reducing time spent in detection and courtship (J.C. Petherick, pers. comm.).

Relocation of bulls

Herd bulls, particularly in extensive herds, may originate from vastly different environments. Bulls are often transported large distances and during transport may be exposed to extreme weather, crowding, physical trauma and irregular feeding and watering. On arrival, bulls may face intense competition from existing bulls, different handling procedures and new diseases. Problems associated with relocation, such as reduced pregnancy rates or delayed calving dates, may not be apparent for 12 months or more. There are cases where 40–50% of bulls failed a BBSE within months of delivery to Northern Territory (McCool and Holroyd 1993) and northern Queensland (Holroyd *et al.* 2005) properties after being purchased from central Queensland sales. The reasons for the failures are not clear as there was little data on the bulls before relocation. Some failures were related to low levels of normal sperm, independent of breed, age and source, but providing bulls experience favourable nutritional and managerial conditions over the next six months ~80% of them are likely to subsequently pass a BBSE (Holroyd *et al.* 2005). Subsequent detailed experiments found minimal effects from relocation on semen traits, either short- or long-term, and concluded that depressions in bull fertility associated with relocation were most likely due to poor relocation management practices (Holroyd *et al.* 2005).

Recommendations to minimise subfertility associated with relocation of bulls are (McCool and Holroyd 1993):

- buy locally whenever possible;
- buy yearling bulls to allow environmental adaptation before mating;
- relocate bulls from afar in the early dry season when pastures are good and arbovirus activity is on the decline;
- introduce bulls to their new environment gradually by holding and feeding in yards initially, then releasing into small paddocks under supervision;
- follow good biosecurity practices (Chapter 13).

Age of first mating of bulls

The age at which bulls are first mated depends upon breed and environment. In southern Australia, *Bos taurus* breeds predominate and bulls are first mated in three categories, as yearlings (15 months), at 18–20 months of age or as two-year-olds (27 months) (R. Holmes, pers. comm.). Many of these matings are as single-sires. In recent years there has been a trend for initial mating at 18–20 months, as yearling bulls require a higher plane of nutrition to reach sexual maturity at 15 months. The calving period in southern Australia is split between autumn (March–April) and spring (August–September) (Chapter 10). The autumn-born bulls are joined in the spring and the spring-born bulls are joined in the autumn. This system does not require the high levels of nutrition needed for yearling bulls and there seem to be fewer problems with penile warts and balanoposthitis and less antagonistic behaviour than with two-year-old bulls. The majority of bulls in northern Australia are *Bos indicus* or *Bos indicus*-derived and are generally mated first as two-year-olds (26–29 months of age) or older and tend to be used in multiple-sire groups. The difference in age of first mating between the two genotypes reflects that *Bos taurus* reach puberty and sexually maturity earlier, and tend to be managed in the more nutritionally favoured areas.

Mating bulls as yearlings has advantages providing herd fertility rates are not compromised. It can accelerate genetic improvement through mating a bull at an earlier age, and younger bulls are easier to handle than older bulls. Despite the effect of poor nutrition on pubertal development, several studies indicate that there is a proportion of *Bos indicus* and tropically adapted bulls that are sexually mature as yearlings and some yearling bulls appear to have similar capabilities of siring calves in a three-month mating period as older bulls (Holroyd *et al*. 2005). However, in most cases resulting pregnancy rates were lower than those achieved by two-year-old bulls because yearling bulls had reached puberty but not sexual maturity.

Managing bulls between matings

A post-breeding BBSE identifies unsound bulls and enables treatable problems to be addressed before next mating. When not in mating, bulls should be managed to ensure optimal performance in their next mating. Emphasis should be placed on maintaining body condition, controlling parasites and diseases and preventing injury. Bulls should be kept in homogenous groups in paddocks large enough for adequate exercise and establishment of individual territories and with protection, such as shade trees, from extreme conditions.

Culling of bulls

As a bull ages, it is more prone to damage of the reproductive organs or physical problems such as arthritis which can prevent service. The longer the bull is kept in the herd, the lower is the bull cost per calf produced. The benefits from keeping a bull longer must be balanced against replacing the bull with one that it is genetically superior. Therefore, to retain a bull in the herd to an old age, the bull must be fertile and genetically equal to, or better than, more recent bull replacements.

The average working life of a bull is about three years. Hence culling bulls at six to seven years of age after three to four years of use is a reasonable compromise between lowered selection intensity and decreased generation interval for genetic gain and an increased risk of infertility (Entwistle 1984). The incidence of reproductive abnormalities increases sharply over five years of age, as does the incidence of bulls chronically infected with campylobacteriosis and trichomoniasis. Ladds *et al*. (1973) found, in an abattoir survey of 550 bulls in northern Australia, that 50% had some form of pathological lesion which may interfere with reproductive performance.

NATURAL MATING SYSTEMS

Each year ~95% of female cattle are naturally mated, i.e. not using assisted breeding technologies such as artificial insemination and embryo transfer, as assisted breeding programs involve greatly increased managerial inputs and costs. However, there are distinct reasons for doing assisted breeding programs (discussed below).

Mating systems

There are two types of natural mating systems, continuous or all-year mating where bulls remain with the breeding herd throughout the year, and restricted (i.e. controlled, seasonal) mating systems where the bulls are introduced to the breeding herd for a period of months and then removed. Restricted mating is more appropriate where the level of management is high, close to all cattle can be mustered and cattle can be segregated effectively (Fordyce 1990). A recent survey found that 73% of properties in the more extensive areas of the Northern Territory and northern Western Australia continuously mated compared to 28% in northern Queensland, 13% in western Queensland and nil in south-east Queensland (McCosker *et al*. 2011a).

Continuous mating in the extensive northern environments is advantageous because (Fordyce 1990):

- peaks of conceptions can move with the seasons where the onset of the wet season in summer can be variable. Conception patterns are highly correlated with rainfall in the previous month (Holroyd *et al*. 1979). With controlled mating, late rainfall may significantly reduce conception rates;
- keeping bulls in the herd reduces the probability of conceptions by either a neighbour's or mickey bulls;
- it maximises the number of calves. Births may be spread throughout the year although they tend to be concentrated in the October–March period.

Restricted mating is considered more efficient for reproductive performance. The major objective of restricted mating is to match the peak nutritional demands of the lactating cow with the peak nutrient in the pasture. Restricted mating aims to prevent dry-season lactation rather than restrict the calving period. The advantages of restricted mating are (Fordyce 1990):

- avoiding out-of-season calves;
- simplification of many management procedures such as vaccination, pregnancy testing, weaning and supplementation;
- preventing early conceptions in maiden heifers;
- improved bull control, which helps control of venereal diseases;
- more uniform progeny groups in age and weight, which facilitates their management and marketing.

There are few figures on comparative reproductive performance of continuous and restricted mated herds. Fordyce (1990) reported weaning rates can be 10% lower in herds mated for three months in some years in north Queensland, partially due to the late start of the wet season significantly delaying the onset of new pasture growth.

Start and length of mating

Mating time and length aim to match nutritional needs of the breeding female with the availability of pasture supply both in quality and quantity. There are incremental changes in the nutritional requirements of females as they advance through pregnancy and into peak lactation (the optimum time for reconception of lactating cows, to avoid a prolonged intercalving period). Lactating cows and their calves are nutritionally the most vulnerable in the herd. A 400 kg lactating cow requires ~50–100% more metabolisable energy to maintain liveweight than if she was dry, with the range depending on milk yield. Part of the extra energy demand is met by increased intake associated with lactation but this is generally insufficient to meet all the energy demands of lactation. As a consequence, maternal tissues are mobilised to provide energy for milk synthesis and thus liveweight loss is inevitable (Hunter 1991).

In northern Australia, peak nutritional conditions occur within a few weeks of the start of the wet season in summer (October–January) with a gradual decline until the start of the next wet season. Mating commences from November to January onwards for five to seven months or longer with peak calving October to February. Calves are weaned at the end of the growing season from March onwards. The start of mating is critical, the length is less critical. In most northern regions an optimum time to finish mating is at the end of the growing season, as this means that almost all calves can be weaned at the first muster in the following year. Many producers go beyond this time hoping for late-calving cows to conceive as a result of weaning at the end of the growing season (Fordyce 1990).

In southern Australia, there are two main periods of growth, one in autumn and one in spring, separated by a period of low growth in winter. Summer is generally dry (with the exception of the northern coast, tableland and slopes regions of New South Wales) and irrigation is used in some districts to extend the pasture growing season into the late spring and summer. Mating commences about August, with most cows traditionally calving in the following autumn–winter (April–June) for the sale of vealers or late winter–spring for the sale of weaners (Chapter 10). Data from Tasmania showed that later-calving September systems were significantly less profitable than earlier-calving systems when selling weaners (Counsell *et al.* 2006).

The length of mating dictates the spread of calving. There are several advantages of minimising the calving spread (Fordyce 1990):

- marketing is easier as stock are closer in age, thus more uniform in weight;
- cows calving earlier relative to the beginning of mating have a greater probability of reconception;
- heifer calves born later in the calving season tend to be older at puberty (Johnston *et al.* 2009).

Modelling has demonstrated the profitability of minimising calving spread in intensive herds (Wilkins 2006). The ideal calving distribution should be 65% of calves born in the first three weeks, followed by 20% and 10% in the two subsequent three-weekly periods, thus 95% of cows to calve in a nine-week period (MLA 2011). To achieve this, mating should be three cycles or 63 days. This allows all females to have a minimum of two oestrous cycles during mating. With extensive herds, removing bulls even for two to three months (at the second round muster) until December can make a big difference in tightening up calving spread and reducing out-of-season calvings.

Size and management of mating groups

The effects of size of the mating group and reproductive performance are poorly researched. There are many factors dictating the size of the mating group including size of property, stocking rate, terrain, number of cattle that can be processed through a yard on a daily basis, labour availability and labour costs.

Bulls should be introduced to the breeding paddock simultaneously to provide better opportunities for them to establish territories (Petherick 2005). In extensive herds, depending on seasonal conditions and topography, bulls can be walked or trucked in November–January and left as small groups at watering points, either at the start of mating or some weeks beforehand which avoids problems associated with an early onset of the wet season and cows being isolated by flooding. Removal of bulls is generally done when the breeding herd is mustered to the yards. It can be extremely difficult to remove bulls from the breeding herd in the paddock.

It is inadvisable to introduce a new bull in an existing breeding herd as resident bulls will have established territories and the new bull will either be excluded or have to fight resident bulls in order to establish a territory. The length of time in the herd is correlated with social dominance; it is likely that the new bull will become the most subordinate of the group and thus sire fewer calves.

There is limited information on the effect of topography, location of water sources and natural barriers influencing the distribution of bulls and females coming together for mating and whether there are effects on paternity. The relationship between a bull's fertility and the size of the home range could result from more females being in the bull's home range because of better-quality pasture or bulls with high fertility covering a larger area seeking females (Fordyce *et al*. 2002).

Composition of mating groups

Should heifers be mated with, separate from or ahead of the main herd? Fordyce (1996) proposed that females up to 3.5 years of age in extensive herds require different management from that of mature cows:

- heifers and first lactation cows need greater nutrient input than mature cows for simultaneous growth and reproduction;
- unless bull control is sound in extensive herds, a proportion of heifers will be prematurely impregnated with their initial lactation in the dry season, resulting in prolonged post-partum anoestrus and higher survival risk;
- mating for heifers is recommended for only three to four months finishing at the first round in April–May even where mating of cows is continuous.

Bull:female ratio

Mating reproductively sound bulls at a ratio 2.5% of cycling females is probably adequate for *Bos indicus* and *Bos indicus*-cross bulls under conditions of low to moderate dispersion in northern Australia (Fordyce *et al*. 2002). This recommendation should be viewed in relation to the herd size. An 80 female herd requires two bulls; a 400 female herd requires 10 bulls. Should there be an issue with one bull during mating, reducing bull numbers by one could have consequences for a herd of 80 females but not for a herd of 400 females. With intensive herds, even lower bull:female ratios (BFR) of one bull to 50–60 females or more are acceptable providing bulls pass a BBSE.

Libido may be affected by BFR because mating activity increases with the number of females in oestrus and sexual activity is stimulated when there are multiple bulls (Petherick 2005). Increasing the BFR to 6% resulted in increased aggression and bull injuries (Fordyce *et al*. 2002) and reduced sexual activity (Price and Wallach 1991).

Single-sire or multiple-sire matings

Single-sire mating overcomes problems with agonistic behaviour between bulls and identification of paternity of progeny. However, fertility could be compromised if, in a single-sire mating, the bull is subfertile or infertile. Even with multiple-sire matings there could be adverse effects on herd fertility if the dominant male is subfertile or infertile and able to prevent subordinate bulls from mating (Petherick 2005).

Paternity of calves in a multiple-sire mating system can be determined by DNA parentage analysis except in the cases of closely related sires. In a study of several properties in northern Australia, resolution of paternity was 92–100% and averaged 98% across sites. This included 10% of calves with no potential sires in any of the mating; the reasons were bulls or cows jumping fences, cows pregnant pre-joining, precocious bull calves and the mixing of calf groups (Holroyd *et al*. 2002).

Composition of bull groups

Age *per se* is unlikely to affect fertility provided bulls are sexually mature, physically able to mate and producing sufficient normal sperm. Rather, the social interactions between bulls of different ages may have adverse effects with older bulls dominating the younger and potentially restricting access of subordinate bulls to females (Petherick 2005). If bulls in groups are of a similar age and are reared together there are fewer injuries from fighting but not necessarily more equal paternity in multiple-sire mated herds (Holroyd *et al*. 2002).

There is evidence that older bulls are more efficient in their sexual behaviour, performing less mounts to the number of serves. This could be an effect of experience. It is difficult to separate the effects of experience and age as learning is associated with age but it appears that young beef bulls need to learn the correct mount orientation through mounting experience (Petherick 2005). Providing sexual experience to bulls increases sexual activity and number of serves. Younger subordinate bulls act as oestrus-detectors then are displaced by the dominant bulls, which then mate (Fritz *et al*. 1999). It is possible that older and more experienced bulls have a greater ability to determine the optimum time for mating than younger less experienced bulls and do not need to spend time determining the receptivity of the females by repeatedly mounting them (Petherick 2005).

ASSISTED REPRODUCTIVE TECHNOLOGIES FOR BEEF CATTLE

Assisted reproductive technologies can significantly increase the number of progeny by a particular male or female and, providing this is combined with genetic evaluation, lead to a much higher rate of genetic gain of desirable traits. Assisted reproductive technologies can be classified as follows (Raadsma and Tammen 2005):

- semen preservation and AI – this is used for distribution of elite male genetics with low disease risk. Its global success is from developments in freezing and transport and improved disease diagnostics;
- single-sex progeny – in certain situations, producing progeny of one sex is desirable. Sexing of embryos and semen is possible but the widespread use of sexed semen is constrained by its increased cost and reduced conception rates;
- multiple ovulation and embryo transfer (MOET) – this is a well-established technique. Variability in the number of viable offspring per program and the small increase in progeny per female (typically two to three times) relative to cost have been barriers to uptake of the technology;
- in vitro production of embryos – large numbers of immature oocytes (eggs) can be collected from females as early as 10–12 weeks of age. These are then cultured and matured in a laboratory. There has been only limited adoption of this technology in the Australian beef industry in contrast to its widespread use in Brazil;
- nuclear transfer (cloning) – differentiated somatic cells of target animals are collected, cultured and injected into an oocyte. Through electrical stimulation the membranes of the somatic cell and the oocyte are fused, cultured and transferred to a surrogate dam. Current methods are very inefficient with a high rate of pregnancy loss and post-natal survival is poor, making this technology far removed from commercial application at this stage.

The two commercially available techniques, AI and embryo transfer, are discussed in more detail.

Artificial insemination

AI, also known as artificial breeding (AB), is the physical placement of semen into the reproductive tract of females to produce a pregnancy by means other natural breeding. The upper level of conception rates for AI programs is ~70% with a realistic target of one live calf per two straws of semen used. An estimated 1.5 million beef and dairy cows in Australia are bred annually by AI with significantly more of them in intensively managed systems. Less than 1% of beef females in northern Australia are bred by AI annually (M.R. McGowan, unpublished). The following sections on AI and embryo transfer were based on the detailed review of Dunn *et al*. (2005).

Advantages of AI

- It provides access to a wide range of bulls selected on superior genetic traits. AI provides the simplest means of generating sire linkages for genetic improvement schemes such as Group Breedplan, which could not exist without AI.
- AI allows the cheaper importation and exportation of superior genetics through transportation of semen and embryos compared with live animal movements, due to cost and quarantine restrictions.
- AI allows maximum use of superior sires. With natural service, a bull should sire ~200 calves in its lifetime. With AI there is an exponential increase in progeny because of cryopreservation of semen in small volumes (0.25–0.5 mL). It can be frozen for years and can be used long after the death of superior bulls.
- The impact of venereal diseases in inseminated animals is reduced. Vaccination of back-up bulls and the herd against vibriosis is still required.
- AI insures against death or injury of the bull. Should a bull be injured and not be able to mount, semen can still be collected by electroejaculation.
- AI allows the introduction of breeds into harsh environments where bulls of those breeds may have difficulty in surviving.
- AI provides improved management benefits. The number of bulls on property is reduced, particularly older bulls which are more difficult to manage. AI will concentrate calving dates and uniform calf crops. Successful AI requires accurate records on individual animals. A beneficial sequel is that overall herd management improves as comprehensive records of many individual cows become available.

Disadvantages of AI

- It requires additional costs and demands on management to provide skills and labour for oestrus detection, storage of semen, insemination and record-keeping.
- There is the low possibility of widespread transmission of genetic faults through semen from one sire. Extensive monitoring of donor bulls is done to minimise the risk of disease, chromosomal abnormalities and poor performance of growth, fertility and carcass traits.

Economics of AI programs

A cost comparison between AI and natural mating programs will differ according to the enterprise and environment. AI requires additional labour, improved equipment and infrastructure, increased handling, improved nutrition, semen, drug synchronisation costs and AI equipment and inseminators. Offsetting these costs are the additional value of the progeny and future genetic improvement of the herd. There will be reduced investment in maintaining and replacing herd bulls. Evans (1991) calculated that the breeding costs for a live calf in a synchronised AI and a MOET program was about five and 47 times respectively, compared to that of natural mating. For a 100 cow herd, Angus Australia (2012) estimated a cost per calf of $73 from AI compared to $47 for a naturally bred calf by a purchased above-average bull.

Planning and conducting an AI program

An AI program should only be undertaken if there are well-defined benefits and commitment by owners and staff to achieve success. There are significant managerial inputs needed before, during and after the actual insemination procedure. The best time and type of program, such as observed natural heats or synchronised programs, should be evaluated. Small paddocks for observation and oestrus detection should be close to insemination facilities. There may be a need for backup bulls after AI to mate with cows that did not conceive.

Selection of females

This requires detailed planning up to 12 months in advance. The reproductive tract of potential females should be examined by manual palpation and ultrasonography to detect the presence of a CL, good uterine tone and absence of pregnancy. Cyclicity cannot be determined in all animals on one observation and females may require a second examination 10 days later. Females should be gaining weight for six weeks before and six weeks after AI for best results. Poor temperament females should not be used. Sexually mature heifers are the female of choice as there are more managerial problems inseminating lactating cows with calves at foot. All females should be tested free of, or vaccinated against, the common reproductive diseases.

Oestrous (heat) detection

Accurate detection of oestrus is the most important criterion for a successful AI program. Irrespective of inseminator competence, standard of facilities and nutrition, an AI program will fail with wrong insemination times. Visual detection of oestrus is the most accurate method with detection rates of 70% by experienced operators (Callesen 2002). Other methods should be used as an aid rather than a replacement to visual signs. Heat mount detectors are devices glued on the midline of the cow's back between the hip bones. There is either release of a coloured dye or the exposure of a coloured panel in response to sustained pressure from being repeatedly mounted by other cows. Tail paint works in a similar way. A chinball harness is a halter attached to a teaser animal; the chinball contains ink which is streaked on the mounted animal as the teaser dismounts. A teaser, usually a male, is either sterilised or incapable of service and is used to detect heat by observing their mounting activity. Examples of teasers are vasectomised or bilateral cryptorchid bulls but there are possible issues with venereal transmission of disease. Sidewinders are bulls where there is surgical relocation of the penis thus preventing intromission on mounting. There are ethical and welfare issues with this procedure and teasers are generally used with *Bos indicus* cattle where heat detection is more difficult. An alternative to teaser bulls are steers treated with injections of oestrogens, a technique that has been successful in the dairy industry (Sawyer and Fulkerson 1981).

A minimum of one hour per 100 cows per day should be spent detecting oestrus. Most *Bos taurus* females display signs of oestrus at or around sunrise and sunset. *Bos indicus* cattle do not display oestrus as readily as *Bos taurus*. The majority of *Bos indicus* commence oestrus at night so observations then as well as morning and evening are required. Providing cattle aren't too scattered, observations in small paddocks where cattle tend to be more relaxed are better than in small confined yards.

Oestrous synchronisation of females

Oestrous synchronisation involves the use of veterinary drugs to concentrate, to a few days, the period when females show signs of oestrus. Unless oestrous synchronisation is used, detection has to be done daily until all cows have displayed oestrus. This could take at least three weeks. Synchronisation still requires heat detection and is a more efficient use of labour providing there is no fatigue from inseminating too many cows in one day. The two main procedures of synchronisation are either prolonging or shortening the luteal phase of the oestrous cycle.

- Prolonging the luteal phase involves the use of synthetic progesterone or progestogens (progesterone-like) drugs either as implants inserted into the vagina (controlled internal drug releasing device [CIDR]) or subcutaneous implants in the ear (e.g. Crestar®) to

mimic the CL. The implants are left in place usually for six to 10 days. After removal there may be a further injection of oestradiol/prostaglandin/equine chorionic gonadotrophin depending on the synchronisation program, with oestrus occurring in two to three days.
- Terminating the luteal phase of the ovary involves injecting synthetic drugs which mimic prostaglandin which regresses the CL. A CL is present between about days 5 and 17 of the oestrous cycle, representing ~50–55% of cycling heifers and cows at any one time. Females outside these times are either developing a CL, which will require a second injection to regress, or are naturally regressing (day 18+). While there are various protocols for the use of prostaglandin (Dunn *et al.* 2005), the most cost-effective method is probably the 10-day program:
  - days 1–5 – observe and inseminate those cows on heat;
  - day 5 – inject with prostaglandin all cows not on heat or that have not been inseminated;
  - days 6–10 – inseminate cows on heat, most being on heat on days 7–9.

Fixed time AI (FTAI) is an alternate strategy involving synchronising ovulation so all females are inseminated at a pre-determined time without doing oestrous detection (Butler 2011). Progesterone implants combined with injections of prostaglandin, oestrogen compounds and equine chorionic gonadotrophin are used. FTAI is very useful in *Bos indicus* females because of the greater difficulty in heat detection. Up to 200 females is a manageable group in good facilities with adequate labour, allowing insemination in a four-hour window on day of AI. Conception rates following FTAI in *Bos indicus*-cross heifers appear to be ~20% less than in conventional synchronisation programs (Butler *et al.* 2011), possibly due to the protocols being developed for use in *Bos taurus* (McGowan *et al.* 2011). Ongoing work is addressing this issue as FTAI may lift AI usage in extensive herds.

Semen-handling and insemination techniques

Semen-handling techniques involve an understanding of the correct procedures for maintenance of liquid nitrogen containers as well as thawing and loading straws, the insemination procedure itself and the rigorous hygiene standards required. These techniques are described in Dunn *et al.* (2005) and there are several training companies and government organisations that provide AI training courses.

Embryo transfer

Embryo transfer (ET) allows genetically superior females to produce more progeny than by natural mating or AI. A sexually mature female (donor) is superovulated using injections of purified FSH to produce many ova rather than the normal one per ovulation, hence the term MOET (multiple ovulation and embryo transfer – common usage has shortened this abbreviation to ET). These ova are fertilised either by insemination or natural service and removed (flushed) from the uterus usually before hatching of the blastocyst (six to eight days after AI). The embryos are transferred into the uterus of a surrogate dam (recipient) which has been synchronised to be at the same day of the oestrous cycle as the donor on the day of embryo collection. There is an international trade in the importation and exportation of frozen embryos.

Steps in an ET program

Selection of both donors and sires is on genetic superiority and reproductive efficiency. The donor should have previously conceived readily, had normal oestrous cycles and calved without difficulty. The donor needs to be reproductively examined to ensure non-pregnancy, and freedeom from abnormalities of the reproductive tract. Similarly, recipients need to be reproductively sound and disease-free. Recipient breed is generally not important although there is a preference for dairy types except in cattle tick regions. Pelvic size of the recipient is important, particularly if the embryo is from a large beef breed. Usually, young cows which have previously had a calf are preferred for non-surgical transfers.

Both donors and recipients should have two normal oestrous cycles before commencement of the ET program. The donor is superovulated under veterinary supervision with multiple injections of FSH. Drugs such as prostaglandin and progesterone can modify the cycle to ensure correct timing for flushing. The recipient must be at exactly the same stage of the oestrous cycle as the donor for successful development of the embryo. A parallel synchronisation program to that of the donor is used.

The donor is inseminated several times during oestrus. Usually, embryos are collected non-surgically six to eight days after the onset of oestrus. Embryos are collected after insertion of a Foley catheter through the cervix. A cuff on the catheter is inflated, flushing fluid is administered via the catheter into the uterus, the fluid in each uterine horn is massaged per rectum towards the tip of the catheter and the fluid with the embryos is drained into a collection vessel. On average about five viable embryos are collected but up to 30 is possible. The embryos are then assessed for viability. The embryos can be transferred immediately (fresh), after being refrigerated for several days or after being cultured for several days during which they continue to develop, or they can be frozen for later use.

There are two methods of transferring embryos. Surgical transfer is where the embryo is transferred into the uterine horn through a laparotomy incision usually in the flank. Most embryos are now transferred by a non-surgical technique similar to AI. The resultant calf has the genes of the donor (not of the recipient) and of the sire.

RECORDS AND RECORDING SYSTEMS FOR REPRODUCTIVE PERFORMANCE

Regular strategic monitoring of the performance of animals in the breeding herd is the key to identification of superior animals and measurement of genetic progress in the herd. Deriving trait values for monitoring performance, selecting and culling cattle requires collection and analysis of data. Fundamental to this is sound record-keeping (Bertram *et al*. 2000a). Data collected must be suitable for the breeding objectives, stored in a time- and cost-effective system that is simple to use and that can be easily accessed, used for analyses and used for other issues such as quality assurance or diagnosis of productivity problems.

A prerequisite of data recording is an effective animal identification (ID) system. An individual ID must be unique, unambiguous, easily used in field sheets and easily marked on animals and tags. An ID code could be at least a six-digit number where the first two digits denote the year of branding and the next four or more is the individual within the year group. There is increasing use of the National Livestock Identification System (NLIS) tag or rumen bolus as a means of on-property data recording of reproductive information. Each NLIS tag is printed with a unique number for whole-of-life identification of that animal.

All data should be linked to an animal ID and, where appropriate, to a date. Data are collated into files which provide the following (Fahey *et al*. 2000):

- unique information such as pedigree, weaning and disposal dates and reasons;
- growth data including weight, condition, height and carcass data;
- female reproduction including annual details of mating outcome;
- male reproduction including scrotal circumference and additional details of breeding soundness examinations, and mating;
- treatments including management groups, paddocks, preventative or production treatments and illnesses.

Breedplan is an electronic genetic evaluation system for beef cattle. It uses genetic evaluation systems based on best linear unbiased prediction to produce estimated breeding values (EBVs) for a range of production traits (Chapter 17). These can be broadly categorised into weight, fertility/calving, carcass and other traits such as docility, net feed intake (Chapter 18), structural soundness and flight time. The main fertility traits that are recorded include scrotal size, days to calving, gestation length and calving ease. Several commercially available computer programs compatible with Breedplan, including Herdmaster, Stockbook and CattleLink, are suitable for electronic submission of performance information and importation of updated EBVs.

The level of data recording is considerably less in extensive than in intensive herds. The average EBV accuracy of young Brahman and Santa Gertrudis bulls is reasonable for growth (60%) but very low for reproduction (25%); the main reason for the low accuracies is that too few herds record reproductive traits and, as heritability of female reproductive traits tend to be low, more records are needed to achieve higher accuracies (Johnston 2011; Chapter 17). For most northern breeds, the key profit drivers under genetic control are sale weight, retail yield and reproduction. Johnston (2011) listed a simple four-step recording strategy aimed at collecting data for these key traits for northern breeds:

- for all cows at start of mating each year (especially the maidens and first lactation cows), record start of mating date, type of mating, mating group (paddock, bull ID), pregnancy test results (especially if culled for being empty) and calving outcome (date of birth, sex, pedigree);
- at weaning, weigh and flight time test (a temperament score is also possible) of all calves and cows;
- for young bulls 15–18 months of age, record weight, scrotal circumference and other BBSE data and ultrasound scan for fat and muscle attributes (although fat depths are likely to be low and with low variation);
- for young heifers, if calving at two years, measure at 15 months, record weight, fat and muscle attributes, mating group details (dates, bull, paddock) then date

of calving and calving outcome. If first calving at three years, measure the above traits at 18 months;

It is important to measure as many traits as possible and, most importantly, to measure all animals, not just those retained. More comprehensive recording could include birth weight, calving difficulty scores and AI date for gestation length. Future recording may include traits for heifer age at puberty from ultrasound scans, semen morphology and teat and udder scores.

INVESTIGATING CAUSES OF POOR REPRODUCTIVE PERFORMANCE

Investigations should involve competent professionals such as cattle veterinary practitioners, agricultural consultants and financial advisers. The InCalf framework for making decisions for optimal reproductive performance was developed for the Australian dairy industry (Dairy Australia 2013) and it applies equally to beef cattle (McGowan and Lane 2003; McGowan and Holroyd 2008).

Step 1: Assess the current reproductive performance of the herd and assess reproductive wastage

Measures such as pregnancy rate, calving rate and weaning rate provide useful estimates of overall performance. Alone, these measures are of limited value unless combined with estimates of rate of conception or conception patterns, whether this is the numbers that conceive on a monthly basis in a continuously mated herd or numbers that conceive within six to nine weeks of a restricted mating period. These estimates can be derived by foetal ageing at pregnancy diagnosis and/or recording calving dates along with condition score, lactation status and age of each female processed. This type of information not only defines the overall herd performance but also defines what proportion of the herd is performing suboptimally.

The first step in addressing foetal and calf losses is to accurately diagnose the cause of each abortion and calf death. Because diagnosis of pre-natal and peri-natal mortalities is often difficult, a thorough process of history-taking, necropsy, laboratory assistance and follow-up is required (Larson 2006). On-farm examination and sample collection from an aborted foetus or dead calf is a job for a cattle veterinarian, with the preferred specimens for an abortion investigation being the foetus and placenta. However, these are only found occasionally. If the whole foetus cannot be sent chilled to a laboratory overnight, a detailed veterinary examination should be done in the field. The placenta should also be examined and a representative selection of cotyledons (fresh and fixed) taken. In the absence of foetal specimens, blood should be collected from at least 10–12 females representing both aborting and normal (pregnant) animals. Rectal examination of all cows is strongly recommended to establish the true dimension of the problem. Any discharges from the reproductive tract can be collected into sterile containers. When there are significant numbers of females returning to service in the period that corresponds to mid-pregnancy, examination of the bull is warranted. Preputial samples should be collected for campylobacteriosis and trichomoniasis diagnosis (Kirkland and Walker 2000).

Step 2: Benchmark the herd performance

The current performance needs to be compared to the median of its performance over past years. Often this is not possible, but published guidelines for average reproductive performance for the region/district can be used. Wherever possible a comparison should be made with a similarly managed herd. Data from large populations can be used as a reference (Wilkins 2006; Holmes Sackett 2010; McCosker *et al.* 2011b; McGowan *et al.* 2013). The performance of the upper 25th percentile herd provides an achievable target for each measure of performance (McGowan *et al.* 2013). An assessment of the economic benefit of improvement to either the next quartile or to the achievable target can be made.

Step 3: Estimate the contribution of each identified factor to herd reproductive performance

Consider both the likely magnitude of the effect in animals exposed to the factor and the frequency with which animals are exposed. For example, compare the effect on herd performance of a heifer which experiences a severe dystocia and subsequently has prolonged post-partum anoestrus versus 50% of first lactation females calving in poor body condition. Epidemiological studies can provide a very useful guide to the herd-, cow- and bull-level factors most likely to be exerting moderate to large effects on herd performance. Prioritising the factors that have the greatest effect on a herd's performance enables the veterinarian and producer to focus on what needs to be done immediately and in the future.

Step 4: Using standardised economic models, estimate the financial outcome of controlling or modifying identified factors

Having identified the key factors most affecting a herd's reproductive performance, the options to modify or manipulate these factors can be considered. The decision, with respect to which option(s) should be adopted, must be based on the estimated costs, benefits and practicality of implementing each option.

Step 5: Monitor the impact on reproductive performance of changes and where necessary modify or add to the original options adopted

This is the most important step and it must be continuously addressed to ensure success in achieving the breeding objective of the property. In developing approaches to improving the reproductive performance of herds, there is a need to understand how and why cattle producers make decisions (Chapter 20). There is a need to clearly appreciate the short- and longer-term consequences of management changes, acknowledging both potential positive and negative outcomes. These changes must be made in the context of the overall farming operation and must be tailored to the objectives and capabilities of each business.

REPRODUCTIVE MANAGEMENT SYSTEMS

The chapter has concentrated on the principles influencing reproductive performance which then affects reproductive management. Putting these principles into practice to optimise reproductive performance for the different Australian environments is illustrated by the following references:

- strategies to optimise reproductive performance in extensive herds in northern Australia (Braithwaite and de Witte 1999a, b; Braithwaite 2004; Burns *et al*. 2010);
- Brahman reproduction in the dry tropics of north Queensland (Anon 2011a);
- achieving higher reproductive performance in Santa Gertrudis in southern Queensland (Anon 2011b);
- improving reproductive performance in southern Australia (MLA 2011);
- management of beef breeding cows in southern Australia (Graham 2011);
- a systems approach to heifer management in southern Australia (Manning 2006);
- selecting for on-farm productivity and flexibility in South Australia (Anon 2011c);
- production systems in south-west WA (Anon 2011d).

DEDICATION

This chapter is dedicated to the late Professor Keith Entwistle who, but for his untimely death in 2011, was the obvious choice to lead this chapter. Such was his knowledge and experience in reproductive studies, particularly in northern Australia, that he was very highly regarded by scientists, students and producers alike. Keith had a profound impact on progressing reproductive efficiency in Australian beef herds.

REFERENCES

Amann RP (1983) Endocrine changes associated with onset of spermatogenesis in Holstein bulls. *Journal of Dairy Science* **66**, 2606–2622. doi:10.3168/jds.S0022-0302(83)82135-3.

Anderson VJ (1990) Factors affecting conception rates of beef cows in the spear grass region of north Queensland. MSc thesis. James Cook University, Townsville.

Angus Australia (2012). *Artificial Insemination for Commercial Producers*. <http://angusaustralia.com.au/>.

Anon (2011a) Case study: Brahman reproduction at Gundaroo. *Beef Bulletin*, December, 18. <http://www.beefcrc.com/publications/beef-bulletin-magazine.html>.

Anon (2011b) Case study: driving fertility in the north. *Beef Bulletin*, December, 19. <http://www.beefcrc.com/publications/beef-bulletin-magazine.html>.

Anon (2011c) Case study. *Beef Bulletin*, December, 9. <http://www.beefcrc.com/publications/beef-bulletin-magazine.html>.

Anon (2011d) Case study. *Beef Bulletin*, December, 17. <http://www.beefcrc.com/publications/beef-bulletin-magazine.html>.

Arteaga A, Baracaldo M, Barth AD (2001) The proportion of beef bulls in western Canada with mature spermiograms at 11 to 15 months of age. *Canadian Veterinary Journal. La Revue Veterinaire Canadienne* **42**, 783–787.

Bagshaw PA, Ladds PW (1974) A study of the accessory sex glands of bulls in abattoirs in northern Australia. *Australian Veterinary Journal* **50**, 489–495. doi:10.1111/j.1751-0813.1974.tb14053.x.

Barth AD, Oko RJ (1989) *Abnormal Morphology of Bovine Spermatozoa*. Iowa State University Press, Ames.

Barth AD, Brito LFC, Kastelic JP (2008) The effect of nutrition on sexual development of bulls. *Theriogenology* **70**, 485–494. doi:10.1016/j.theriogenology.2008.05.031.

Bertram J, Edmonston V, Fahey G, Fawcett G, Greenup A, Hill F, Jackson D, Taylor K, Thompson R, Tierney M, Tyler R, Whittle R, Allen J, Burrow H (2000a) *Beef Cattle Recording and Selection*. Department of Primary Industries, Brisbane.

Bertram JD, McGowan MR, Doogan VJ, Phillips NJ (2000b) Preliminary studies of criteria for selecting of young tropically adapted bulls. In *Proceedings of the Australian Association of Cattle Veterinarians Conference*, Perth, pp. 130–132. Australian Cattle Veterinarians, Brisbane.

Bertram JD, Fordyce G, McGowan MR, Jayawardhana GA, Fitzpatrick LA, Doogan VJ, De Faveri J, Holroyd RG (2002)

Bull selection and use in northern Australia 3. Serving capacity tests. *Animal Reproduction Science* **71**, 51–66. doi:10.1016/S0378-4320(02)00025-8.

Best M (2007) *The Economics of Beef in Central Queensland: Gross Margins and Production Notes*. Department of Primary Industries and Fisheries, Brisbane.

Blockey MAdeB (1976) Sexual behaviour of bulls at pasture: a review. *Theriogenology* **6**, 387–392. doi:10.1016/0093-691X(76)90105-9.

Blockey MAdeB (1979) Observations on group mating of bulls at pasture. *Applied Animal Ethology* **5**, 15–34. doi:10.1016/0304-3762(79)90004-X.

Blockey MAdeB (1989) Relationship between serving capacity of beef bulls as predicted by the yard test and their fertility during paddock mating. *Australian Veterinary Journal* **66**, 348–351. doi:10.1111/j.1751-0813.1989.tb09729.x.

Blockey MAdeB, Straw WM, Jones LP (1981) Heritability of scrotal circumference and serving capacity of bulls. In *Proceedings of the Australian Association of Animal Breeding and Genetics* **2**, 224.

Blockey MAdeB, Taylor EG (1984) Observations on spiral deviation of the penis in beef bulls. *Australian Veterinary Journal* **61**, 141–145. doi:10.1111/j.1751-0813.1984.tb07217.x.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005) The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management. *Australian Journal of Experimental Agriculture* **45**, 1075–1091. doi:10.1071/EA03097.

Braithwaite I (2004) Cattle veterinarians: influencing producer profitability? In *Proceedings of the Australian Cattle Veterinarians Conference,* Canberra, pp. 39–46. Australian Cattle Veterinarians, Brisbane.

Braithwaite ID, de Witte KW (1999a) Strategies to optimise beef cattle production in north Australia. In *Proceedings of the Australian Cattle Veterinarians Conference,* Hobart, pp. 232–249. Australian Cattle Veterinarians, Brisbane.

Braithwaite ID, de Witte KW (1999b) A practical management template for improved decision-making in north Australian beef cattle production. In *Proceedings of the Australian Cattle Veterinarians Conference,* Hobart, pp. 250–261. Australian Cattle Veterinarians, Brisbane.

Burgess GW, Chenoweth PJ (1975) Mid-piece abnormalities in bovine semen following experimental cases of bovine ephemeral fever. *British Veterinary Journal* **131**, 536–543.

Burns BM, Fordyce G, Holroyd RG (2010) A review of factors that impact on the capacity of beef cattle females to conceive, maintain a pregnancy and wean a calf: implications for reproductive efficiency in northern Australia. *Animal Reproduction Science* **122**, 1–22. doi:10.1016/j.anireprosci.2010.04.010.

Burrow HM (2003) Selecting female cattle. In *Proceedings of the Australian Cattle Veterinarians Conference,* Cairns, pp. 65–71. Australian Cattle Veterinarians, Brisbane.

Butler S (2011) Preparing for pregnancy: artificial insemination guidelines for northern herds. *Frontier, Spring,* 7–8. Meat and Livestock Australia, Sydney.

Butler SAA, Burns BM, Laing A, Dawson K, McGowan MR (2011) Use of fixed-time AI for genetic improvement in northern Australia. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, p. 112. North Australia Beef Research Council, Brisbane.

Callesen H (2002) New breeding techniques in cattle. In *Proceedings of the XII World Buiatrics Congress,* Hannover. (Eds M Kaske, H Scholz and M Holtershinken) pp. 290–299.

Cavalieri L, Van Camp SD (1997) Bovine seminal vesiculitis: a review and update. *Veterinary Clinics of North America. Food Animal Practice* **13**, 233–241.

Chase CC Jr, Larsen RE, Hammond AC, Randel RD (1990) Influence of energy intake on reproductive performance of Senepol and Angus bulls in a subtropical environment. *Journal of Animal Science* **68** (Suppl. 1), 491–492.

Chase CC Jr, Chenoweth PJ, Larsen RE, Olsen TA, Hammond AC, Menchaca MA, Randel RD (1997) Growth and reproductive development from weaning through 20 months of age among breeds of bulls in subtropical Florida. *Theriogenology* **47**, 723–745. doi:10.1016/S0093-691X(97)00030-7.

Chenoweth P (2009) The semen examination. In *Proceedings of the Australian Cattle Veterinarians Conference,* Gold Coast, pp. 179–187. Australian Cattle Veterinarians, Brisbane.

Chenoweth PJ, Petherick JC, Bertram JD (2002) Sexual behaviour in the bull. In *Bull Fertility: Selection and Management in Australia.* (Ed. G Fordyce) pp. 4.1–4.11. Australian Cattle Veterinarians, Brisbane.

Christmas R (2001) Management and evaluation considerations for range beef bulls. In *Topics in Bull Fertility* (Ed. PJ Chenoweth). International Veterinary Information Service, Ithaca. <www.ivis.org>.

Corbet NJ, Burns BM, Corbet DH, Crisp JM, Johnston DJ, McGowan MR, Venus BK, Holroyd RG (2011) Bull traits measured early in life as indicators of herd fertility. In *Proceedings of the Association for the Advancement of Animal Breeding and Genetics.* (Ed. P Vercoe) **19**, 55–58.

Cortese V (2006) Designing vaccination programs for today's herd examination. In *Proceedings of Australian Cattle Veterinarians Conference,* Port Macquarie, pp. 187–193. Australian Cattle Veterinarians, Brisbane.

Cortese VS (2009) Strategies for controlling infectious causes of abortion. In *Proceedings of Australian Cattle Veterinarians Conference,* Gold Coast, pp. 205–207. Australian Cattle Veterinarians, Brisbane.

Coulter GH, Foote RH (1976) Relationship of testicular weight to age and scrotal circumference of Holstein bulls. *Journal of Dairy Science* **59**, 730–732. doi:10.3168/jds.S0022-0302(76)84265-8.

Coulter GH, Kozub GC (1984) Testicular development, epididymal sperm reserves and semen quality in two-year-old Hereford and Angus bulls. *Journal of Animal Science* **59**, 432–440.

Coulter GH, Kozub GC (1989) Efficacy of methods used to test fertility of beef bulls used for multiple-sire breeding under range conditions. *Journal of Animal Science* **67**, 1757–1766.

Coulter GH, Cook RB, Kastelic JP (1997) Effects of dietary energy on scrotal surface temperature, seminal quality, and sperm production in young beef bulls. *Journal of Animal Science* **75**, 1048–1052.

Counsell D, Salmon L, Rhodes T (2006) Profitability of Tasmanian beef enterprises: calving dates and stocking rates for weaner and yearling production. In *Proceedings of Australian Cattle Veterinarians Conference,* Hobart, pp. 211–224. Australian Cattle Veterinarians, Brisbane.

Crowe MA, Padmanabhan V, Mihm M, Beitins IZ, Roche JF (1998) Resumption of follicular waves in beef cows is not associated with periparturient changes in follicle-stimulating hormone heterogeneity despite major changes in steroid and luteinizing hormone concentrations. *Biology of Reproduction* **58**, 1445–1450. doi:10.1095/biolreprod58.6.1445.

Cundiff LV, Gregory KE, Koch RM, Dickerson GE (1986) Genetic diversity among cattle breeds and its use to increase beef production efficiency in a temperate environment. In *Proceedings of 3rd World Congress on Genetics Applied to Livestock Production*. pp. 271–282. University of Nebraska, Lincoln.

D'Occhio MJ (1993) Management of fertility in extensive beef herds: use of gonadotrophin releasing hormone (GnRH) vaccines and GnRH agonists in female cattle. In *Proceedings of Australian Association of Cattle Veterinarians Conference,* Gold Coast, pp. 95–97. Australian Cattle Veterinarians, Brisbane.

D'Occhio MJ, Kinder JE (1993) Predictors of fertility in bulls: relationship to cow fertility. In *Bull Fertility* (Ed. RG Holroyd) pp. 93–97. Conference and Workshop Series QC93008. Department of Primary Industries, Brisbane.

D'Occhio MJ, Fordyce G, Whyte TR, Jubb TF, Fitzpatrick LA, Cooper NJ, Aspden WJ, Bolam MJ, Trigg TE (2002) Use of GnRH agonist implants for long-term suppression of fertility in extensively managed heifers and cows. *Animal Reproduction Science* **74**, 151–162. doi:10.1016/S0378-4320(02)00189-6.

D'Occhio MJ, Hengstberger KJ, Johnston SD (2007) Biology of sperm chromatin structure and relationship to male fertility and embryonic survival. *Animal Reproduction Science* **101**, 1–17. doi:10.1016/j.anireprosci.2007.01.005.

Dairy Australia (2013) *Fertility*. <http://www.incalf.com.au/>.

David JS, Bishop MW, Cembrowicz HJ (1971) Reproductive expectancy and infertility in cattle. *Veterinary Record* **89**, 181–185. doi:10.1136/vr.89.7.181.

de Castro T, Ibarra D, Rodriguez M, Valdez L, Benquet N, Rubianes E (2011) Resumption of postpartum ovarian cyclicity after different suckling manipulation treatments in primiparous beef cows. *Animal Production Science* **51**, 111–114. doi:10.1071/AN10108.

de Witte K, Norman S, McGrath K (2006) *The Dropped Ovary Technique for Spaying Cattle: A Training Manual*. Australian Cattle Veterinarians, Brisbane.

Dixon R (1998) Improving cost-effectiveness of supplementation systems for breeder herds in northern Australia. Final Report, Project DAQ.098. Meat and Livestock Australia, Sydney.

Doogan VJ, Fordyce G, Shepherd RK, James TJ, Holroyd RG (1991) The relationships between liveweight, growth from weaning to mating and conception rate of *Bos indicus* cross heifers in the dry tropics of north Queensland. *Australian Journal of Experimental Agriculture* **31**, 139–144. doi:10.1071/EA9910139.

Dunn B, Fawcett G, Fahey G, Boothby D, Fordyce G (2005) *Artificial Breeding of Beef Cattle: A Practical Guide*. Department of Primary Industries and Fisheries, Brisbane.

Dutra F, Carlsten J, Ekman S (1999) Hind limb skeletal lesions in 12-month-old bulls of beef breeds. *Zentralblatt fur Veterinarmedizin. Reihe A.* **46**, 489–508. doi:10.1046/j.1439-0442.1999.00241.x.

Entwistle KW (1978) Reproduction. In *Beef Cattle Production in the Tropics*. (Eds RM Murray and KW Entwistle) pp. 175–231. James Cook University, Townsville.

Entwistle KW (1983) Factors influencing reproduction in beef cattle in Australia. *Australian Meat Research Review* **43**, 1–30.

Entwistle KW (1984) Practical considerations in beef cattle reproductive programs. *University of Sydney Post-Graduate Foundation in Veterinary Science Proceedings* **68**, 311–328.

Entwistle KW (1990) Nutritional and management techniques for improving reproductive efficiency in beef cattle in northern Australia. In *Proceeding of Australian Association of Cattle Veterinarians Conference*. pp. 131–138. Australian Cattle Veterinarians, Brisbane.

Entwistle K (2002) Bull reproductive anatomy and physiology. In *Bull Fertility: Selection and Management in Australia* (Ed. G Fordyce) pp. 2.1–2.17. Australian Cattle Veterinarians, Brisbane.

Entwistle K, Fordyce G (2003) *Evaluating and Reporting Bull Fertility*. Australian Cattle Veterinarians, Brisbane.

Entwistle KW, Goddard ME (1984) Productivity of some *Bos indicus* genotypes in subcoastal northern Queensland. In *Evaluation of Large Ruminants for the Tropics*. ACIAR Workshop (Ed. JW Copland) pp. 156–160. CSIRO, Rockhampton.

Entwistle K, Holroyd R (1993) Nutritional effects on bull fertility. In *Bull Fertility* (Ed. RG Holroyd), pp. 38–43. Conference and Workshop Series QC93008. Department of Primary Industries, Brisbane.

Evans G (1991) Application of reproductive technology to the Australian livestock industries. *Reproduction, Fertility and Development* **3**, 627–650. doi:10.1071/RD9910627.

Fahey G, Boothby D, Fordyce G, Sullivan M (2000) *Female Selection in Beef Cattle*. Information Series QI00047. Department of Primary Industries, Brisbane.

Fitzpatrick LA (1994) Aspects of postpartum anoestrus in *Bos indicus* cows. PhD thesis. James Cook University, Townsville.

Fitzpatrick LA, Fordyce G, McGowan MR, Bertram JD, Doogan VJ, De Faveri J, Miller RG, Holroyd RG (2002) Bull selection and use in northern Australia. Part 2. Semen traits. *Animal Reproduction Science* **71**, 39–49. doi:10.1016/S0378-4320(02)00024-6.

Fordyce G (1990) Management of beef cattle for optimum fertility. In *Proceedings of Australian Association of Cattle Veterinarians Conference*. pp. 101–120. Australian Cattle Veterinarians, Brisbane.

Fordyce G (1996) Heifer management in north Australia's dry tropics. In *Proceedings of Australian Association of Cattle Veterinarians Conference,* Toowoomba, pp. 79–86. Australian Cattle Veterinarians, Brisbane.

Fordyce G (2006) Practical strategies to reach target mating weight in north Australia beef heifers. In *Proceedings of Aus-*

tralian Cattle Veterinarians Conference, Port Macquarie, pp. 142–152. Australian Cattle Veterinarians, Brisbane.

Fordyce G, Cooper NJ (1995) An evaluation of visual assessment for fertility in Brahman cross cows using the Bonsma technique. *Theriogenology* **43**, 495–507. doi:10.1016/0093-691X(94)00042-S.

Fordyce G, Holroyd RG (2003) Management of extensive northern beef breeding herds. In *Proceedings of Australian Cattle Veterinarians Conference,* Cairns, pp. 16–30. Australian Cattle Veterinarians, Brisbane.

Fordyce G, Tyler R, Anderson VJ (1990) Effect of reproductive status, body condition and age of *Bos indicus* cross cows early in drought on survival and subsequent reproductive performance. *Australian Journal of Experimental Agriculture* **30**, 315–322. doi:10.1071/EA9900315.

Fordyce G, Cooper NJ, Kendall IE, O'Leary BM, de Faveri J (1996a) Creep feeding and prepartum supplementation effects on growth and fertility of Brahman-cross cattle in the dry tropics. *Australian Journal of Experimental Agriculture* **36**, 389–395. doi:10.1071/EA9960389.

Fordyce G, Howitt CJ, Holroyd RG, O'Rourke PK, Entwistle KW (1996b) The performance of Brahman-Shorthorn and Sahiwal-Shorthorn beef cattle in the dry tropics of northern Queensland. 5. Scrotal circumference, temperament, ectoparasite resistance, and the genetics of growth and other traits in bulls. *Australian Journal of Experimental Agriculture* **36**, 9–17. doi:10.1071/EA9960009.

Fordyce G, Fitzpatrick LA, Mullins TJ, Cooper NJ, Reid DJ, Entwistle KW (1997) Prepartum supplementation effects on growth and fertility in *Bos indicus*-cross cows. *Australian Journal of Experimental Agriculture* **37**, 141–149. doi:10.1071/EA96015.

Fordyce G, Fitzpatrick LA, Cooper NJ, Doogan VJ, De Faveri J, Holroyd RG (2002) Bull selection and use in northern Australia. 5. Social behaviour and management. *Animal Reproduction Science* **71**, 81–99. doi:10.1016/S0378-4320(02)00027-1.

Fordyce G, Entwistle K, Norman S, Perry V, Gardiner B, Fordyce P (2006) Standardising bull breeding soundness evaluations and reporting in Australia. *Theriogenology* **66**, 1140–1148. doi:10.1016/j.theriogenology.2006.03.009.

Fordyce G, Anderson A, McCosker K, Williams PJ, Holroyd RG, Corbet NJ, Sullivan MS (2013) Liveweight prediction from hip height, condition score, fetal age and breed in tropical female cattle. *Animal Production Science* **53**, 275–282. doi:10.1071/AN12253.

Fortes MRS, Lehnert SA, Bolormaa S, Reich C, Fordyce G, Corbet NJ, Whan V, Hawken RJ, Reverter A (2012) Finding genes for economically important traits: Brahman cattle puberty. *Animal Production Science* **52**, 143–150. doi:10.1071/AN11165.

Frisch JE (1973) Comparative drought resistance of *Bos indicus* and *Bos taurus* crossbred herds in central Queensland. 2. Relative mortality rates, calf birth weights, and weights and weight changes of breeding cows. *Australian Journal of Experimental Agriculture and Animal Husbandry* **13**, 117–126. doi:10.1071/EA9730117.

Fritz L, Stookey JM, Clavelle JL, Waltz CS (1999) Observations of cattle on extensive range. 1999. Annual report to the Saskatchewan Agricultural Development Fund: Strategic Program Area X: Food Animal Behaviour and Welfare. Cited in Petherick JC (2005) A review of some factors affecting the expression of libido in beef cattle, and individual bull and herd fertility. *Applied Animal Behaviour Science* **90**, 185–205.

Garcia-Winder M, Imakawa K, Day ML, Zalesky DD, Kittok RJ, Kinder JE (1984) Effect of suckling and ovariectomy on the control of luteinizing hormone secretion during the postpartum period in beef cows. *Biology of Reproduction* **31**, 771–778. doi:10.1095/biolreprod31.4.771.

Glaze JB, Vogt DW, Lipsey RJ, Ellersieck MR (1994) Genetic and phenotypic parameter estimates of pelvic measurements and birth weight in beef heifers. *Theriogenology* **41**, 943–950. doi:10.1016/0093-691X(94)90509-H.

Goddard ME, Entwistle KW, Dixon R (1980) Variables affecting pregnancy rate in *Bos indicus* cross cows. *Proceedings of the Australian Society of Animal Production* **13**, 65–67.

Golding RL, Schatz TJ, Jayawardhana GA (2011) Breeder fertility improved through selection in a NT Brahman herd. In *Proceedings of the Northern Beef Research Update Conference*, Darwin, August, p. 113. North Australia Beef Research Council, Brisbane.

Graham J (2011) *Management of Beef Breeding Cows*. Department of Primary Industries. <http://www.dpi.vic.gov.au/agriculture/beef-and-sheep/beef/breeding/management-of-beef-breeding-cows>.

Greenough PR, Gacek Z (1987) A preliminary report on a laminitis-like condition occurring in bulls under feeding trials. *Bovine Practitioner* **22**, 176–181.

Griffith MK, Williams GL (1996) Roles of maternal vision and olfaction in suckling-mediated inhibition of luteinizing hormone secretion, expression of maternal selectivity, and lactational performance of beef cows. *Biology of Reproduction* **54**, 761–768. doi:10.1095/biolreprod54.4.761.

Hasker P (2000) *Beef Cattle Performance in Northern Australia: A Summary of Recent Research*. Information Series QI00054. Department of Primary Industries, Brisbane.

Hetzel DJS, Mackinnon MJ, Dixon R, Entwistle KW (1989) Fertility in a tropical beef herd divergently selected for pregnancy rate. *Animal Production* **49**, 73–81. doi:10.1017/S0003356100004268.

Hill BD, Holroyd RG, Sullivan M (2009) Clinical and pathological findings associated with congenital hypovitaminosis A in extensively grazed beef cattle. *Australian Veterinary Journal* **87**, 94–98. doi:10.1111/j.1751-0813.2009.00398.x.

Hoffman DP, Stevenson JS, Minton JE (1996) Restricting calf presence without suckling compared with weaning prolongs postpartum anovulation in beef cattle. *Journal of Animal Science* **74**, 190–198.

Holmes WE (2010) The economics of female reproduction. *Beef Bulletin,* December, 11. <http://www.beefcrc.com/publications/beef-bulletin-magazine>.

Holmes Sackett (2010) *Southern Beef Situation Analysis*. Project B.COM.0255. Meat and Livestock Australia, Sydney.

Holroyd RG (1987) Foetal and calf wastage in *Bos indicus* cross beef genotypes. *Australian Veterinary Journal* **64**, 133–137. doi:10.1111/j.1751-0813.1987.tb09661.x.

Holroyd RG, O'Rourke PK (1989) *Collation of Basic Biological Data on Beef Production in North Australia*. Meat and Livestock Australia, Sydney.

Holroyd RG, Arthur BA, Mayer BG (1979) Reproductive performance of beef cattle in north-western Queensland. *Australian Veterinary Journal* **55**, 257–262.

Holroyd RG, Doogan VJ, De Faveri J, Fordyce G, McGowan MR, Bertram JD, Vankan DM, Fitzpatrick LA, Jayawardhana GA, Miller RG (2002) Bull selection and use in northern Australia. 4. Calf output and predictors of fertility of bulls in multiple-sire herds. *Animal Reproduction Science* **71**, 67–79. doi:10.1016/S0378-4320(02)00026-X.

Holroyd RG, Bertram JD, Doogan VJ, Fordyce G, Petherick JC, Turner LB (2005) Bullpower: delivery of adequate normal sperm to site of fertilisation. Final Report NAP3.117. Meat and Livestock Australia, Sydney.

Holroyd RG, Bertram JD, Doogan VJ, Fitzpatrick LA, Fordyce G, Petherick JC (2007) Bullpower and beyond: maximising the calf output of bulls. In *Proceedings of the Northern Beef Research Update Conference,* Townsville. (Eds B Pattie and B Restall) pp. 15–20. North Australia Beef Research Council, Brisbane.

Hum S (2007) *Vibriosis in Cattle*. Primefact 451. <http://www.dpi.nsw.gov.au/agriculture/livestock/health>.

Hunter RA (1991) Strategic supplementation for survival, reproduction and growth of cattle. In *Proceedings of 2nd Grazing Livestock Nutrition Conference*, Steamboat Springs, Colorado, pp. 32–47.

Hunter RA, Magner T (1988) The effect of supplements of formaldehyde-treated casein on the partitioning of nutrients between cow and calf in lactating *Bos indicus* x *Bos taurus* heifers fed a roughage diet. *Australian Journal of Agricultural Research* **39**, 1151–1162. doi:10.1071/AR9881151.

Igboeli G, Rakha AM (1971) Puberty and related phenomena in Angoni (short horn Zebu bulls). *Journal of Animal Science* **33**, 647–650.

Jeffery M, Loxton I, Van der Mark S, James T, Shorthose R, Bell K, D'Occhio M (1997) Liveweight gains, and carcass and meat characteristics of entire, surgically spayed or immunologically spayed beef heifers. *Australian Journal of Experimental Agriculture* **37**, 719–726. doi:10.1071/EA97074.

Jephcott S, Norman S (2004) *Pregnancy Diagnosis in Cattle*. Australian Cattle Veterinarians, Brisbane.

Jeyaruban MG, Wolcott ML, Johnston DJ, Graser H-U (2011) Effect of previous reproductive status of dam on the preadjustment of weaning weight for genetic evaluation in tropical breeds. In *Proceedings of Association for the Advancement of Animal Breeding and Genetics.* (Ed. P Vercoe) **19**, 59–62.

Johnston D (2011) Accelerating gains: practical application of selection of cattle for northern Australia. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, pp. 69–72. North Australia Beef Research Council, Brisbane.

Johnston DJ, Barwick SA, Corbet NJ, Fordyce G, Holroyd RG, Williams PJ, Burrow HM (2009) Genetics of heifer puberty in two tropical beef genotypes in northern Australia and associations with heifer- and steer-production traits. *Animal Production Science* **49**, 399–412. doi:10.1071/EA08276.

Johnston DJ, Barwick SA, Fordyce G, Holroyd RG (2010) Understanding the genetics of lactation anoestrus in Brahmans to enhance genetic evaluation of female reproductive traits. In *Proceedings of the 10th World Conference on Genetics Applied to Livestock Production,* Leipzig, 1–6 August, Communication 923.

Johnston D, Grant T, Walkley J, Prayaga K (2012) Early predictors of lifetime female reproductive performance. Final Report B.NBP.0363. Meat and Livestock Australia, Sydney.

Jolly PD, McSweeney CS, Schlink AC, Houston EM, Entwistle KW (1996) Reducing post-partum anoestrous interval in first-calf *Bos indicus* crossbred beef heifers. III. Effect of nutrition on response to weaning and associated variation in metabolic hormone levels. *Australian Journal of Agricultural Research* **47**, 927–942. doi:10.1071/AR9960927.

Jonker FH (2004) Fetal death: comparative aspects in large domestic animals. *Animal Reproduction Science* **82–83**, 415–430. doi:10.1016/j.anireprosci.2004.05.003.

Kinder JE, Roberson MS, Wolfe MW, Stumpf TT (1994) Management factors affecting puberty in the heifer. In *Factors Affecting Calf Crop.* (Eds MJ Fields and RS Sand) pp. 55–68. CRC Press, Boca Raton.

Kirkland PD, Walker KH (2000) Bovine abortion: making a diagnosis from the laboratory. In *Proceedings of the Australian Cattle Veterinarians Conference,* Perth, pp. 191–193. Australian Cattle Veterinarians, Brisbane.

Kirkland PD, Fordyce G, Holroyd R, Taylor J, McGowan M (2009) Impact of infectious diseases on beef cattle reproduction. Final Report B.AHW.0042. Meat and Livestock Australia, Sydney.

Kroker G, Clarke L (2000) *Control of Calving Difficulty in Heifers.* <http://www.dpi.vic.gov.au/agriculture/beef-and-sheep/beef/breeding/control-of-calving-difficulty-in-beef-heifers>.

Ladds PW, Dennett DP, Glazebrook JS (1973) A survey of genitalia of bulls in northern Australia. *Australian Veterinary Journal* **49**, 335–340. doi:10.1111/j.1751-0813.1973.tb06825.x.

Lamond DR (1970) The influence of undernutrition on reproduction in the cow. *Animal Breeding Abstracts* **38**, 359–372.

Lane SM, Kiracofe GH, Craig JV, Schalles RR (1983) The effect of rearing environment on sexual behaviour of young beef bulls. *Journal of Animal Science* **57**, 1084–1089.

Larson R (2006) Reducing calf mortality in beef herds. In *Proceedings of the Australian Cattle Veterinarians Conference,* Port Macquarie, pp. 58–65. Australian Cattle Veterinarians, Brisbane.

Laster DB, Glimp HA, Gregory KE (1972) Age and weight at puberty and conception in different breeds and breedcrosses of beef cattle. *Journal of Animal Science* **34**, 1031–1036.

Letchford PJ (2010) How to spay. In *Proceedings of the Australian Cattle Veterinarians Conference,* Alice Springs, pp. 90–100. Australian Cattle Veterinarians, Brisbane.

Lew-Tabor A (2010) Update on Australian *Campylobacter fetus* subspecies *venerealis* diagnostic research. In *Proceedings of the 3rd AVA/NZVA Pan Pacific Veterinary Conference,* Brisbane, PC27b.4.

Lindsay JA, Ndama PH, Tune DR, Toleman MA, Entwistle KW (1982) Protected proteins as supplements for bulls fed tropical forage diets. *Proceedings of the Australian Society of Animal Production* **14**, 594.

Lunstra DD (1982) Testicular development and onset of puberty in beef bulls. Beef Research Program, Progress Report No. 1, pp. 26–27. Roman L Hruska US Meat Animal Research Center, Nebraska.

Lunstra DD, Echternkamp SE (1982) Puberty in beef bulls: acrosome morphology and semen quality in bulls of different breeds. *Journal of Animal Science* **55**, 638–648.

MacDonald N, de Witte KS (2000) Recommendations for campylobacteriosis control in northern herds. *Journal of the Australian Association of Cattle Veterinarians* **13**, 18–19.

Makarechian M, Arthur PF (1990) Effects of body condition and temporary calf removal on reproductive performance of range cows. *Theriogenology* **34**, 435–443. doi:10.1016/0093-691X(90)90002-B.

Manning R (2004) Heifer management. In *Proceedings of the Australian Cattle Veterinarians Conference,* Grindelwald, pp. 97–110. Australian Cattle Veterinarians, Brisbane.

Manning R (2006) A systems approach to heifer management. In *Proceedings of the Australian Cattle Veterinarians Conference,* Port Macquarie, pp. 105–119. Australian Cattle Veterinarians, Brisbane.

Maree L, Casey NH, Jacobi JE (1989) The non-significant effect of feeding level, growth rate and age on libido of young Afrikaner bulls. *Journal of the South African Veterinary Association* **60**, 143–144.

Matthews B, Morton J (2011) Accuracy of predicting calving dates in dairy cattle. In *Proceedings of the Australian Cattle and Reproduction Veterinarians Conference,* Launceston, p. 178. Australian Cattle Veterinarians, Brisbane.

Mayer DG, McKeon GM, Moore AD (2012) Prediction of mortality and conception rates of beef breeding cattle in northern Australia. *Animal Production Science* **52**, 329–337. doi:10.1071/AN11204.

McConochie J (2007) *Selecting and Managing Beef Heifers.* Primefact 626. Department of Primary Industries, Walgett, NSW.

McCool C, Holroyd R (1993) Mating practices. In *Bull Fertility* (Ed. RG Holroyd). Conference and Workshop Series QC93008, pp. 50–51. Department of Primary Industries, Brisbane.

McCosker K, Letchford P, Petherick JC, Mayer D, McGowan M (2010) Morbidity, mortality and body weight gain of surgically spayed, yearling Brahman heifers. *Australian Veterinary Journal* **88**, 497–503. doi:10.1111/j.1751-0813.2010.00646.x.

McCosker K, Fordyce G, Smith D, Burns B, Jephcott S, McGowan M (2011a) Survey of selected north Australian beef breeding herds: 1. Management. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, p. 120. North Australia Beef Research Council, Brisbane.

McCosker KD, McGowan MR, O'Rourke PK, Smith DR, Fordyce G, Burns BM, Joyner D, Phillips N, Menzies D, Newsome T, Perkins NR, Morton JM, Jephcott S (2011b) Cash cow: exposing northern breeder herd productivity. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, pp. 19–23. North Australia Beef Research Council, Brisbane.

McGowan MR (1991) Arbovirus infections associated with reproductive loss in cattle. In *Proceedings of the Australian Cattle Veterinarians Conference,* Sydney, pp. 17–18. Australian Cattle Veterinarians, Brisbane.

McGowan MR (1998) Brief review of infectious causes of reproductive failure in beef herds. In *The North Australia Program: 1998 Review of Reproduction and Genetics Projects.* NAP Occasional Publication No. 8 (Ed. S Blakeley). Meat and Livestock Australia, Sydney.

McGowan MR (2003) The impact of leptospirosis on the reproductive performance of beef herds. In *Proceedings of the Australian Cattle Veterinarians Conference,* Cairns, pp. 94–99. Australian Cattle Veterinarians, Brisbane.

McGowan MR, Holroyd RG (2008) Reproductive inefficiencies and opportunities in dairy and beef cattle in Australia. *Proceedings of the Australian Society of Animal Production* **27**, 1–9.

McGowan MR, Kirkland PD (2003) The control of viral infections affecting the reproductive performance of cattle. In *Proceedings of the Australian Association of Cattle Veterinarians Conference,* Cairns, pp. 86–93. Australian Cattle Veterinarians, Brisbane.

McGowan MR, Lane L (2003) Strategies to achieve high calving rates and short concentrated calving periods in beef herds. In *Proceedings of the Australian Association of Cattle Veterinarians Conference,* Cairns, pp. 6–13. Australian Cattle Veterinarians, Brisbane.

McGowan MR, Bertram JD, Fordyce G, Fitzpatrick LA, Miller RG, Jayawardhana GA, Doogan VJ, De Faveri J, Holroyd RG (2002) Bull selection and use in northern Australia. 1. Physical traits. *Animal Reproduction Science* **71**, 25–37. doi:10.1016/S0378-4320(02)00023-4.

McGowan MR, Fordyce G, Holroyd RG (2011) Recent advances in beef cattle reproduction: how science will improve herd performance. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, pp. 11–18. North Australia Beef Research Council, Brisbane.

McGowan M, Fordyce G, McCosker K, Smith D, O'Rourke P, Perkins N, Newsome T, Menzies D, Jephcott S, Maraquart L, Barnes T (2013) Northern Australian Beef Fertility Project: cash cow. Final Report B.NBP.0382. Meat and Livestock Australia, Sydney.

McSweeney CS, Kennedy PM, D'Occhio MJ, Fitzpatrick LA, Reid D, Entwistle KW (1993) Reducing post-partum anoestrous interval in first-calf *Bos indicus* crossbred beef heifers. 2. Responses to weaning and supplementation. *Australian Journal of Agricultural Research* **44**, 1079–1092. doi:10.1071/AR9931079.

Micke GC, Sullivan TM, Rolls PJ, Hasell B, Greer RM, Norman ST, Perry VEA (2010) Dystocia in 3-year-old beef heifers: relationship to maternal nutrient intake during early- and mid-gestation, pelvic area and hormonal indicators of placental function. *Animal Reproduction Science* **118**, 163–170. doi:10.1016/j.anireprosci.2009.08.006.

MLA (2011) *More Beef from Pastures. Module 6: Weaner Throughput.* Meat and Livestock Australia, Sydney.

Montiel F, Ahuja C (2005) Body condition and suckling as factors influencing the duration of postpartum anestrus in cattle: a review. *Animal Reproduction Science* **85**, 1–26. doi:10.1016/j.anireprosci.2003.11.001.

Moran C, Quirke JF, Roche JF (1989) Puberty in heifers: a review. *Animal Reproduction Science* **18**, 167–182. doi:10.1016/0378-4320(89)90019-5.

Morris CA (1980) A review of relationships between aspects of reproduction in beef heifers and their lifetime production. 2. Associations with relative calving date and with dystocia. *Animal Breeding Abstracts* **48**, 753–767.

Morris CA, Amyes NC (2005) Response to selection for age at puberty in an Angus herd. In *Proceedings of the Association for the Advancement of Animal Breeding and Genetics*. (Ed. K Prayaga) **16**, 157–160.

Muller T, Lisle A, Fordyce G, Holroyd R, Doogan V, McGowan M (2010) Scrotal size in tropically adapted beef bulls in northern Australia. *Australian Cattle Veterinarian* **54**, 26.

Mwansa PB, Makarechian M (1991) The effect of postweaning level of dietary energy on sex drive and semen quality of young beef bulls. *Theriogenology* **35**, 1169–1178. doi:10.1016/0093-691X(91)90363-I.

Ndama PH, Entwistle KW, Lindsay JA (1983) Effect of protected protein supplements on some testicular traits in Brahman cross bulls. *Theriogenology* **20**, 639–650. doi:10.1016/0093-691X(83)90184-X.

Niethe GE, Holmes WE (2008) Modelled female sale options demonstrate improved profitability in northern beef herds. *Australian Veterinary Journal* **86**, 458–464. doi:10.1111/j.1751-0813.2008.00366.x.

Nolan CJ, Neuendorff DA, Godfrey RW, Harms PG, Welsh TH, McArthur NH, Randel RD (1990) Influence of dietary energy intake on prepubertal development of Brahman bulls. *Journal of Animal Science* **68**, 1087–1096.

Norman ST (2002) Factors influencing the incidence of dystocia in beef heifers. PhD thesis. University of Queensland, Brisbane.

Norman ST (2006) The management of dystocia in cattle. In *Proceedings of the Australian Cattle Veterinarians Conference,* Port Macquarie, pp. 70–81. Australian Cattle Veterinarians, Brisbane.

Norman ST, Parry SD, Ladds PW, Brown A (2002) The identification and management of reproductive diseases of bulls. In *Bull Fertility: Selection and Management in Australia.* (Ed. G Fordyce) pp. 8.1–8.24. Australian Cattle Veterinarians, Brisbane.

O'Rourke PK, Winks L, Kelly AM (1992) *North Australia Beef Producer Survey 1990.* Meat and Livestock Australia, Sydney.

Oswin S (2000) Leptospirosis: an update on control through vaccination. In *Proceedings of the Australian Cattle Veterinarians Conference,* Perth, pp. 182–187. Australian Cattle Veterinarians, Brisbane.

Oswin S (2011) Bopriva®: A bovine anti-GnRF vaccine – a new approach to meat quality and behavioural control for bulls and heifers. *Australian Cattle Veterinarian* **59**, 17

Ott RS (1986) Breeding soundness examination of bulls. In *Current Therapy in Theriogenology 2*. (Ed. DA Morrow) p. 131. WB Saunders, Philadelphia.

Parkinson TJ (2011) Bull evaluation in NZ beef and dairy herds. In *Proceedings of the Australian Cattle and Reproduction Veterinarians Conference,* Launceston, pp. 119–131. Australian Cattle Veterinarians, Brisbane.

Perry VEA, Chenoweth PJ, Post TB, Munro RK (1990a) Fertility indices for beef bulls. *Australian Veterinary Journal* **67**, 13–16. doi:10.1111/j.1751-0813.1990.tb07383.x.

Perry VEA, Munro RK, Chenoweth PJ, Bodero DAV, Post TB (1990b) Relationships among bovine male and female reproductive traits. *Australian Veterinary Journal* **67**, 4–5. doi:10.1111/j.1751-0813.1990.tb07380.x.

Perry V, Phillips N, Fordyce G, Gardiner B, Entwistle K, Chenoweth P, Doogan VJ (2002) Semen collection and evaluation. In *Bull Fertility: Selection and Management in Australia.* (Ed. G Fordyce) pp. 5.1–5.19. Australian Cattle Veterinarians, Brisbane.

Persson Y, Soderquist L (2005) The proportion of beef bulls in Sweden with mature spermiograms at 11–13 months of age. *Reproduction in Domestic Animals* **40**, 131–135. doi:10.1111/j.1439-0531.2005.00567.x.

Persson Y, Soderquist L, Ekman S (2007) Joint disorder: a contributory cause to reproductive failure in beef bulls? *Acta Veterinaria Scandinavica* **49**, 31–37. doi:10.1186/1751-0147-49-31.

Petherick JC (2005) A review of some factors affecting the expression of libido in beef cattle, and individual bull and herd fertility. *Applied Animal Behaviour Science* **90**, 185–205. doi:10.1016/j.applanim.2004.08.021.

Petherick JC, McCosker K, Mayer DG, Letchford P, McGowan M (2013) Evaluation of the impacts of spaying by either the dropped ovary technique or ovariectomy via flank laparotomy on the welfare of *Bos indicus* beef heifers and cows. *Journal of Animal Science* **91**, 382–394. doi:10.2527/jas.2012-5164.

Pfizer (2013) *Welcome to BVDV Australia.* <https://www.bvdvaustralia.com.au/home/default.aspx>.

Price EO, Wallach SJR (1991) Inability to predict the adult sexual performance of bulls by prepubertal sexual behaviors. *Journal of Animal Science* **69**, 1041–1046.

Pruitt RJ, Corah LR (1985) Effect of energy intake after weaning on the sexual development of beef bulls. 1. Semen characteristics and serving capacity. *Journal of Animal Science* **61**, 1186–1193.

Quintans G, Vazquez AI, Weigel KA (2009) Effect of suckling resumption with nose plates and premature weaning on postpartum anestrous interval in primiparous cows under range conditions. *Animal Reproduction Science* **116**, 10–18. doi:10.1016/j.anireprosci.2008.12.007.

Raadsma HW, Tammen I (2005) Biotechnologies and their potential impact on animal breeding and production: a review. *Australian Journal of Experimental Agriculture* **45**, 1021–1032. doi:10.1071/EA05073.

Radostits OM, Gay CC, Blood DC, Hinchcliff KW (2000) *Veterinary Medicine. A Textbook of the Diseases of Cattle, Sheep, Pigs, Goats and Horses.* 9th edn. WB Saunders, Sydney.

Randel RD (1981) Effect of once-daily suckling on postpartum interval and cow-calf performance of first-calf Brahman x Hereford heifers. *Journal of Animal Science* **53**, 755–757.

Rekwot PI, Oyedipe EO, Akerejola OO, Kumi-Diaka J, Umoh JE (1987) The effect of protein intake on the onset of puberty in Bunaji and Friesian x Bunaji crossbred bulls in Nigeria. *Theriogenology* **28**, 427–434. doi:10.1016/0093-691X(87)90247-0.

Rekwot PI, Oyedipe EO, Akerejola OO, Kumi-Diaka J (1988) The effect of protein intake on body weight, scrotal circumference and semen production of Bunaji bulls and their Friesian crosses in Nigeria. *Animal Reproduction Science* **16**, 1–9. doi:10.1016/0378-4320(88)90002-4.

Richards MW, Spitzer JC, Warner MB (1986) Effect of varying levels of postpartum nutrition and body condition at calving on subsequent reproductive performance in beef cattle. *Journal of Animal Science* **62**, 300–306.

Rudder TH, Seifert GW, Burrow HM (1985) Environmental and genotype effects on fertility in a commercial beef herd in central Queensland. *Australian Journal of Experimental Agriculture* **25**, 489–496. doi:10.1071/EA9850489.

Saacke RG, Nadir S, Nebel RL (1994) Relationship of semen quality to sperm transport, fertilisation and embryo quality in ruminants. *Theriogenology* **41**, 45–50. doi:10.1016/S0093-691X(05)80047-0.

Sambraus HH (1980) Imprinting in farm animals: implications for sexual behaviour. *Bovine Practice* **1**, 8–9.

Saul GR, Baud SR, McDonald JW, McRae C, Clark AJ (1982) A comparison of the growth rate and carcase characteristics of steers and heifers when entire, spayed, pregnant or fitted with an intravaginal device. *Australian Journal of Experimental Agriculture and Animal Husbandry* **22**, 258–263.

Sawyer GJ, Fulkerson WJ (1981) The effectiveness of steers and heifers treated with oestrogen or testosterone to detect oestrus in cattle. *Animal Reproduction Science* **3**, 259–269. doi:10.1016/0378-4320(81)90001-4.

Scaramuzzi RJ, Baird DT, Campbell BK, Driancourt M-A, Dupont J, Fortune JE, Gilchrist RB, Martin GB, McNatty KP, McNeilly AS, Monget P, Monniaux D, Vinoles C, Webb R (2011) Regulation of folliculogenesis and the determination of ovulation rate in ruminants. *Reproduction, Fertility and Development* **23**, 444–467. doi:10.1071/RD09161.

Schatz TJ (2011) Understanding and improving heifer fertility in northern Australia. MSc thesis. Charles Darwin University, Darwin.

Schatz T (2012) *Heifer Management in Northern Beef Herds*. (Ed. I. Partridge). Meat and Livestock Australia, Sydney.

Schatz TJ, Jayawardhana GA, Golding R, Hearnden MN (2010) Selection for fertility traits in Brahmans increases heifer rates from yearling mating. *Animal Production Science* **50**, 345–348. doi:10.1071/AN09165.

Schatz T, McCosker K, Fordyce G, McGowan M (2011a) Predicting pregnancy rates from pre-calving body condition score of first-lactation females. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, p. 117. North Australia Beef Research Council, Brisbane.

Schatz TJ, Jayawardhana GJ, Golding RL (2011b) Selection improves fertility in a Brahman herd. In *Proceedings of the Northern Beef Research Update Conference,* Darwin, August, p. 118. North Australia Beef Research Council, Brisbane.

Schillo KK, Hall JB, Hileman SM (1992) Effects of nutrition and season on the onset of puberty in the beef heifer. *Journal of Animal Science* **70**, 3994–4005.

Schlink AC, Gibson DS, Liang ZL, Dixon R (1988) Calf management strategies and reproductive performance in a northern Australian cattle herd. In *Proceedings of the Australian Society of Animal Production* **17**, 326–329.

Schlink AC, Houston EM, Entwistle KW (1994) Impact of long term early weaning on the productivity of *Bos indicus* cross cows. *Proceedings of the Australian Society of Animal Production* **20**, 339.

Seifert GW, Rudder TH (1976) The genetic implications of selecting cattle for larger size. In *Principles of Beef Production*. (Eds H Swan and WH Broster) pp. 373–386. Butterworths, London.

Senger PL (2003) *Pathways to Pregnancy and Parturition*. 2nd edn. Current Conceptions, Pullman, WA.

Shephard RW (2005) The sensitivity and specificity of single manual examination tests for detection of corpora lutea in the ovaries of non-cycling cows. *Australian Veterinary Journal* **83**, 572–576. doi:10.1111/j.1751-0813.2005.tb13341.x.

Short RE, Adams DC (1988) Nutritional and hormonal interrelationships in beef cattle reproduction. *Canadian Journal of Animal Science* **68**, 29–39. doi:10.4141/cjas88-003.

Silver GV, Price EO (1986) Effects of individual vs. group rearing on the sexual behaviour of prepubertal beef bulls: mount orientation and sexual responsiveness. *Applied Animal Behaviour Science* **15**, 287–294. doi:10.1016/0168-1591(86)90099-7.

Stagg K, Diskin MG, Sreenan JM, Roche JF (1995) Follicular development in long-term anoestrous suckler beef cows fed two levels of energy postpartum. *Animal Reproduction Science* **38**, 49–61. doi:10.1016/0378-4320(94)01354-O.

Stagg K, Spicer LJ, Sreenan JM, Roche JF, Diskin MG (1998) Effect of calf isolation on follicular wave dynamics, gonadotrophin and metabolic hormone changes, and interval to first ovulation in beef cows fed either of two energy levels postpartum. *Biology of Reproduction* **59**, 777–783. doi:10.1095/biolreprod59.4.777.

Sullivan RM, O'Rourke PK, Robertson DJ, Cooke D (1992) Effects of once-yearly weaning on some aspects of herd productivity in an extensive herd in the semi-arid tropics of northern Australia. *Australian Journal of Experimental Agriculture* **32**, 149–156. doi:10.1071/EA9920149.

Tegegne A, Entwistle KW, Mukasa-Mugerwa E (1992) Nutritional influences on growth and onset of puberty in Boran and Boran x Friesian bulls in Ethiopia. *Theriogenology* **37**, 1005–1016. doi:10.1016/0093-691X(92)90099-D.

Tyler R, Fordyce G (1988) Assessing the survival risk of cows prior to drought. *Proceedings of the Australian Society of Animal Production* **17**, 478.

Tyler R, English B, Sullivan M, Jackson D, Matthews R, Holmes B, MacDonald N, Oxley T, Leigo S (2012) *Weaner Management in Northern Beef Herds*. (Ed. I Partridge). Meat and Livestock Australia, Sydney.

Van Demark NL, Mauger RE (1964) Effect of energy intake on reproductive performance of dairy bulls. I. Growth, reproductive organs and puberty. *Journal of Dairy Science* **47**, 798–802. doi:10.3168/jds.S0022-0302(64)88767-1.

Walker B (2004) *Neospora caninum Infection in Cattle*. AgNote DAI-314. NSW Agriculture. <http://www.dpi.nsw.gov.au/agriculture/livestock/health/specific/cattle/neospora>.

Walker B, McKinnon R (2011) *Bovine Trichomoniasis*. Primefact 1130. Department of Industry and Investment, NSW. <http://www.dpi.nsw.gov.au/agriculture/livestock/health/specific/cattle/bovine-trichomoniasis>.

Wettemann RP (1994) Precalving nutrition/birth weight interaction and rebreeding efficiency. Animal Science Research Report, Oklahoma State University. Cited in Montiel F and Ahuja C (2005) Body condition and suckling as factors influencing the duration of postpartum anestrus in cattle: a review. *Animal Reproduction Science* ***85***, 1–26.

Whitlock BK, Coffman EA, Coetzee JF, Daniel JA (2012) Electroejaculation increased vocalization and plasma concentrations of cortisol and progesterone, but not substance P, in beef bulls. *Theriogenology* **78**, 737–746. doi:10.1016/j.theriogenology.2012.03.020.

Wicksteed LT (1980) A model of beef production systems: central sub-coastal speargrass zone of Queensland. *Proceedings of the Australian Society of Animal Production* **13**, 361–364.

Wildeus S (1993) Age-related changes in scrotal circumference, testis size and sperm reserves in bulls of the tropically adapted Senepol breed. *Animal Reproduction Science* **32**, 185–195. doi:10.1016/0378-4320(93)90090-E.

Wildeus S, Holroyd RG, Entwistle KW (1984) Patterns of pubertal development in Sahiwal and Brahman cross bulls in tropical Australia I. Growth and semen characteristics. *Theriogenology* **22**, 361–373. doi:10.1016/0093-691X(84)90456-4.

Wilkins JF (2006) Constraints to reproductive efficiency in southern Australian beef herds. In *Proceedings of Australian Cattle Veterinarians Conference,* Port Macquarie, pp. 153–162. Australian Cattle Veterinarians, Brisbane.

Williams GL, McVey WR, Hunter JF (1993) Mammary somatosensory pathways are not required for suckling-mediated inhibition of luteinizing hormone secretion and delay of ovulation in cows. *Biology of Reproduction* **49**, 1328–1337. doi:10.1095/biolreprod49.6.1328.

Wolf FR, Almquist JO, Hale EB (1965) Prepubertal behavior and pubertal characteristics of beef bulls on high nutrient allowance. *Journal of Animal Science* **24**, 761–765.

Wright IA, Rhind SM, Russel AJF, Whyte TK, McBean AJ, McMillen SR (1987) Effects of body condition, food intake, and the temporary calf separation on the duration of the post-partum anoestrous period and associated LH, FSH and prolactin concentrations in beef cows. *Animal Production* **45**, 395–402. doi:10.1017/S0003356100002889.

Wright IA, Rhind SM, Whyte TK, Smith AJ (1992) Effects of body condition at calving and feeding levels after calving on LH profiles and the duration of post-partum anoestrous period in beef cows. *Animal Production* **55**, 41–46. doi:10.1017/S0003356100037259.

Zelski R (2007) *Leptospirosis in Cattle Herds*. Primefact 445. Department of Primary Industries, NSW. <http://www.dpi.nsw.gov.au/agriculture/livestock/health/specific/cattle/leptospirosis-cattle-herds>.

15 Grazing and pasture management and utilisation in Australia

J. Earl

INTRODUCTION

Grasslands occupy ~60% of the land surface of Australia (460 million ha) and grazing livestock is the primary land use of this area (Kemp and Michalk 1994). As of June 2011 the national beef cattle herd was 28.5 million head, the off-farm meat value of Australia's beef industry was AUD$11.6 billion and the gross value of cattle production was $7.9 billion (MLA 2012). Ecologically and economically, grasslands are one of the nation's greatest natural assets.

Beef cattle are the predominant grazers across the majority of the area of grazed land. On an equivalent basis (DSE; 1 head = 11 DSE) (McDonald and Orchard 1985) the beef cattle population constituted 78% of the main grazing livestock population, compared to 73.1 million sheep (1 head = 1.2 DSE) (MLA 2012). The management of beef cattle has a critical impact on the health and productive potential of grasslands and pastures.

Grazing management is perhaps the most important strategy available to land managers to regenerate land and increase the productive potential of pastures. Grazing was described most eloquently by Voison (1959) as 'the meeting of cow and grass'. Effective management of that connection requires the manipulation of the complex interaction between grazing livestock, plants and soil to achieve positive change in all elements.

The interaction between grazing management, pasture management and utilisation is the basis of any productive beef cattle enterprise. Management of the cow and grass interaction is also a key contributor to the effective function of key ecosystem elements on a landscape scale. As the potential production of beef from an area is influenced by pasture growth, so too the health of soil and the pasture it supports is influenced by the movement of grazing animals across the landscape.

Soil and pasture are the foundation blocks of a profitable beef enterprise. Understanding the response of plants and pasture to the intensity and frequency of defoliation provides the capacity to use grazing management to enhance pasture growth and production. Regular monitoring and measurement of pasture growth provides the basis for evidence-based decisions regarding grazing and pasture management and is critical to the application of appropriate stock numbers and utilisation.

Grazing and pasture management are integral components of whole farm management and each has a range of approaches. The range of management options will be presented, along with comment on the potential for beef cattle to improve pasture growth and land condition under the various regimes. Ultimately the choice of management approach adopted will come down to the goals of the manager, governed to a large extent by the landscape and the resources available (Chapter 20).

Pasture utilisation is one of the most important elements influencing pasture growth and production. Methods to measure pasture herbage mass (the total volume of forage produced), growth and utilisation and the importance of these measures to sustainable production and soil health are discussed.

While there are several principles relating to the agro-ecosystem which hold across all environments, reference will be made to three production zones – the southern, northern and coastal regions – as appropriate. Challenges to production including soil health, weeds, drought and climate variability and strategies to deal with these issues will be addressed, as well as how grazing management can contribute to reducing the impact of environmental factors which compromise pasture production.

PLANT GROWTH

Although the pasture or paddock is the management unit in a grazing enterprise, the pasture consists of countless individual plants. In a stable perennial pasture, the dominant plant form will be the perennial grasses. The grazing process occurs at the level of individual plants and it is the interaction between the grazing animal and the grass plant which drives change in the pasture. It is the management of the interaction between the animal, plant and soil which defines pasture management. Knowledge of the physiological response of grasses to the intensity and frequency of defoliation provides the basis for understanding changes that occur within the pasture.

Perennial grasses are the backbone of productive pasture systems. Perennial by definition equates to perpetual, constant, permanent, enduring: given adequate environmental conditions, perennial grasses and pastures have the capacity to survive and grow indefinitely. It is the capacity for vegetative reproduction, the ability of perennial grasses to regenerate tillers, which confers perenniality (Brown and Stuth 1993; Fig. 15.1a). Each tiller has the potential to regenerate an additional 10–15 tillers or more in a growing season from the basal meristem (Fig. 15.1b). Potential production in the subsequent growing season depends on management in combination with environmental conditions during the development period and the intensity and frequency of defoliation during the growing period.

All grass species exhibit the same basic sigmoidal growth pattern. Perennial grasses initially start with a period of relatively slow growth (Phase I) until a critical leaf area is attained (Fig. 15.2). As the amount of structural material in the leaf increases, the digestibility and metabolisable energy of the grass plant decreases. During Phase II the rate of growth increases until the plant initiates floral production. Once flowering, the rate of growth slows as assimilates are directed towards reproduction (Phase III) (Fig. 15.3). A key consideration for management of the grazing process is that the optimal time to graze a perennial grass for plant persistence and production is towards the latter part of Phase II, whereas the optimal time to graze the same plant for animal production is at the early stage of Phase II when forage is of higher quality (Chapter 16).

It is important to emphasise that the phase of growth is characteristic of an individual plant at a point in time, rather than of a pasture. The term may be applied to a monoculture pasture but in reality, within a diverse pasture, there will be a range of species present with a

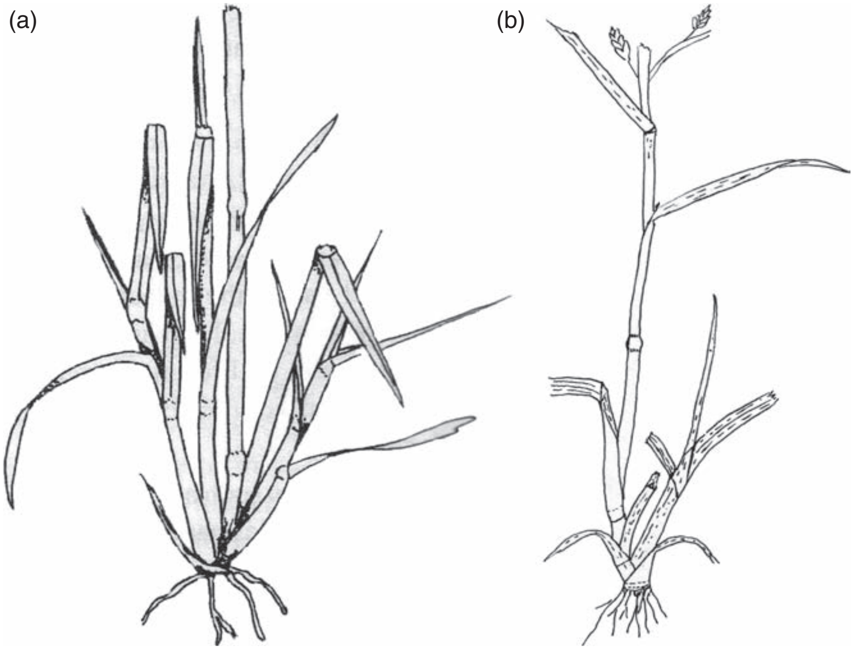


Figure 15.1: (a) Tillers of a perennial grass plant. (b) Growth points of a grass tiller. Source: Adapted from Wheeler *et al.* (2002).

Figure 15.2: Phases of plant growth.

range of specific environmental requirements for growth and production. Different species and potentially individual plants of the same species will exhibit different phases of growth throughout the season.

Environmental factors

There are a vast number of environmental influences on plant growth. A list of the primary factors influencing plant growth is provided in Table 15.1. This is not an exhaustive list but it highlights that many of the factors that influence plant growth are within control of the manager, through grazing and pasture management and careful planning of infrastructure development.

The environmental factors listed in Table 15.1 are generally considered beyond the control of the manager. This underestimates the reach of grazing and pasture management which can influence how much rainfall is retained in the soil profile, to what degree the soil surface temperature fluctuates throughout a 24-hour period, how much green leaf is present to intercept sunlight, the diversity of

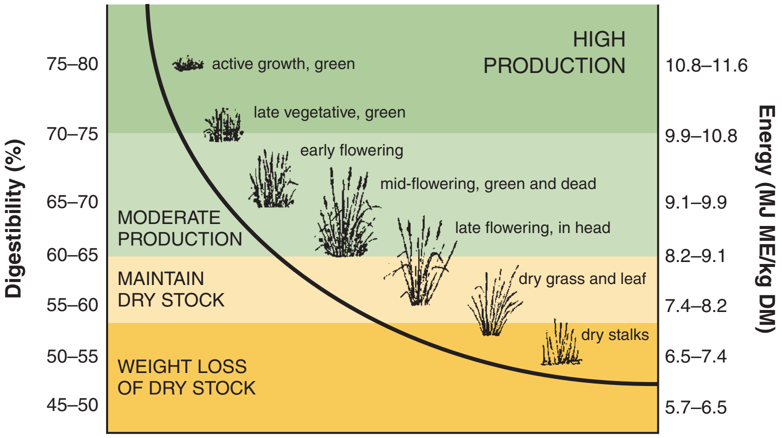


Figure 15.3: Phases of pasture growth, showing changes in digestibility and quality over time. Source: Allan (1994).

Table 15.1: Primary factors that influence plant growth

Environmental factors	Plant factors	Soil factors
Rainfall: amount and distribution	Species	Cation exchange capacity
Temperature	Stage of growth	Fertility and pH
Sunlight: duration and intensity	Height or leaf area	Water-holding capacity
Season	Time since grazed	Water infiltration rate
Soil type	Residual herbage mass	Compaction
Slope	Groundcover	Organic matter and soil carbon
Aspect	Presence of weeds	Biological activity
Proximity to water	Tree cover	Depth of topsoil

species present to effectively extend the growing season and how much organic matter is returned to the soil. More detail on each of these processes is provided later in this chapter.

Defoliation

Defoliation refers to the removal of leaf material of a plant. It may result from fire, physical damage or mechanical harvesting or consumption by grazing animals. The latter process is the focus of this section. Grasses are well adapted to tolerate frequent defoliation by grazing animals and it has been suggested that a mutualistic relationship with herbivores has influenced the evolution of grasses (Owen 1980). The specific adaptive features of grasses include high palatability, capacity for vegetative reproduction and regeneration of photosynthetic material and the location of basal growth points (Owen and Weigert 1981; McNaughton 1983). Although a wide variation exists between species, grasses are generally well adapted to tolerate defoliation.

There are two phases in the physiological response of grasses to defoliation. The immediate effect is the removal of photosynthetic material (Briske and Richards 1994). Within 30 min of defoliation, carbon allocation is towards leaf growth and shoot meristematic regions (Welker *et al.* 1985). Depending on the intensity of defoliation this may occur at the expense of the root system. As leaf area increases, photosynthesis again becomes the primary source of the resources driving growth.

Severe defoliation causes root death within 24 hours, reduction in the weight and diameter of roots and a concentration of roots in the upper layers of the soil but the main effect is in the slowing of leaf growth for an extended period (Troughton 1957). The extent of this series of reactions is directly related to the severity and, to a lesser extent, the frequency of defoliation. After severe defoliation the primary response is the production of new leaf material; with repeated defoliation, eventually root growth stops (Younger 1972).

It is clear that any reduction in leaf area to the extent where insufficient photosynthetic material is retained to provide the energy needed for regeneration of leaf will have an adverse effect on root parameters. When energy for regrowth is provided at the expense of the root system, a plant is considered to be overgrazed. The effect of defoliation on the root system of perennial grasses has important consequences for long-term persistence and production. Any action which reduces the length or depth of roots increases the plant's vulnerability to adverse environmental conditions such as drought. In perennial grasses, the biomass of leaf material above-ground is reflected in root biomass below-ground (Fig. 15.4). Larcher (1995) considered the root system to be the most vulnerable organ of many higher plants.

The rate of regrowth of leaf is dependent on the accumulation of carbon measured as the residual leaf area and the number and location of active shoot meristems (the growing points of the plant). If defoliation is not excessive, carbon may be imported from ungrazed tillers without interrupting assimilate supply to the roots. The allocation strategy depends on the photosynthetic capacity of the residual leaf area (Richards 1993). Regrowth following defoliation is much more rapid when driven by photosynthesis compared to regrowth initiated from meristems.

Figure 15.4: Above-ground leaf material is reflected in the root biomass of perennial grasses. Frequent defoliation reduces leaf area and root density and depth. Source: Jones (2000).

The timing of grazing in relation to the development of tillers will influence regrowth potential. New tillers may be initiated within two to three weeks of grazing, and the length of time remaining in the growing season will determine tiller recruitment and total tiller production in defoliated plants (Butler and Briske 1988). Late-season defoliation may induce bud inhibition in some species, restricting tiller production in the subsequent growing period. The ability to regenerate new tillers confers grazing resistance and is the basis of perenniality in grasses (Brown and Stuth 1993).

Grazing management is essentially management of the balance between intensity and frequency of defoliation. Getting this balance right involves understanding the basis of plant physiological processes, pasture dynamics and animal nutritional requirements, and how these change with varying seasonal and climatic conditions.

Seasonal production: growth cycles

Pasture plants are generally considered to fall into two primary categories, warm season or cool season. Pastures in the southern areas where the majority of rainfall occurs through the winter period are dominated by cool season species and pastures in the northern region with predominant summer rainfall consist primarily of warm season species. Within these main categories there are some variation in patterns of growth.

The most common cool season grass species are introduced (i.e. not native to Australia) and have the C_3 photosynthetic pathway. Native and subtropical species dominate the list of perennial grasses classed as warm season species and usually possess the C_4 photosynthetic pathway. Functionally, the C_4 pathway enables carbon fixation with much reduced water requirement compared to C_3 plants. The primary advantage is that with the high temperatures experienced during summer, in concert with high light and evaporative demand, the water use efficiency of C_4 plants far exceeds that of C_3 species (Johnston 1996). The optimal temperature for photosynthesis in C_3 plants is 10–15°C compared to 30–40°C for C_4. This has important consequences, given the predictions of change in climatic conditions (discussed later in this chapter). Across the more temperate grassland areas, C_3 and C_4 plants coexist and provide diversity and more even seasonal production in pastures. A list of some of the more common warm and cool season perennial grass species is provided in Table 15.2.

Table 15.2: Some of the more common cool and warm season perennial grass species of pastures

Cool season C_3	Warm season C_4
Introduced grasses	*Introduced – subtropical grasses*
Ryegrass, *Lolium perenne*	Green panic, *Panicum maximum*
Fescue, *Festuca arundinacea*	Bambatsi panic, *Panicum coloratum*
Phalaris, *Phalaris aquatica*	Premier digit, *Digitaria eriantha*
Cocksfoot, *Dactylis glomerata*	Rhodes grass, *Chloris gayana*
Prairie grass, *Bromus carthcarticus*	Purple pigeon grass, *Setaria incrassata*
	Naturalised grasses[1]
	Kikuyu, *Pennesetum clandestinium*
	Paspalum, *Paspalum dilatatum*
	Buffel grass, *Cenchrus ciliaris*
Native grasses	*Native grasses*
Wheatgrass, *Elymus scaber*	Mitchell grasses, *Astrebla* spp.
Wallaby grasses, *Rytidosperma* spp.	Queensland bluegrass, *Dichanthium sericeum*
Microlaena, *Microlaena stipoides*	Redgrass, *Bothriochloa macra*
Plume grass, *Dichelachne micrantha*	Lovegrass, *Eragrostis leptostachya*
Corkscrew grass, *Austrostipa scabra*	Parramatta grass, *Sporobolus creber*
Plains grass, *Austrostipa aristiglumis*	Windmill grasses, *Chloris* spp.
Poa tussock, *Poa sieberiana*	Kangaroo grass, *Themeda australis*
	Native sorghum, *Sorghum leiocladum*

[1] Naturalised grasses are defined as exotic species which have not been deliberately sown but are well adapted to the environment where they occur and spread naturally.

The warm season C_4 species dominate over 80% of the grassland area of Australia, primarily through Queensland, northern NSW and the Northern Territory. C_3 species are more common in grasslands on the tablelands of NSW, Victoria, Tasmania and the southern areas of South Australia and south-west Western Australia (Hattersley 1983). Figure 15.5 provides an example of the different growth patterns of some common warm and cool season species of the north coast region of NSW. Note the relatively high growth rates of the C_4 species, such as kikuyu, setaria/rhodes grass during the summer

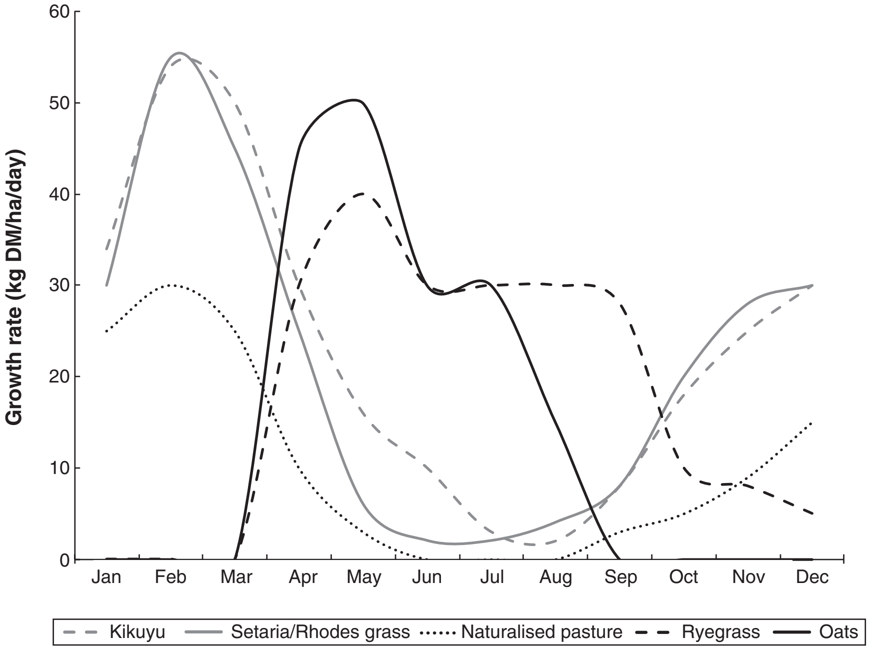


Figure 15.5: Growth curves of some common species of the north coast region of NSW. Source: Adapted from Allan (1994).

months and high growth rates of the C_3 species such as ryegrass and oats during the winter months.

More extensive lists of pasture plants which may be extant or suitable for introduction in different regions and their characteristics are available from other sources, for example MLA's *Pasture Picker Tool* (MLA 2012a). There has been much written in regard to the general productivity, forage quality, drought resilience and persistence of different species. It is extraordinarily difficult to generalise about such factors when these characteristics are so strongly influenced by grazing management and the combined effects of environmental influences such as those listed in Table 15.1. Tables predicting pasture growth rates, such as those in the *NSW Prograze Manual* (Allan 1994), provide a starting point but more conservative estimates are recommended until actual pasture growth rates can be measured by the manager. There is no substitute for actual seasonal pasture measurements recorded from individual paddocks to predict and quantify changes in pasture production on a particular site.

Animal selectivity

One of the greatest influences of grazing livestock is their effect in modifying the competitive balance between plants through selective grazing (Brown and Stuth 1993). Grazing livestock actively select different plant species and plant parts from the pasture sward. Palatability, grazing resistance and competitive ability are continuous variables in grassland species. Often the most palatable species are those that are more tolerant of grazing and more competitive due to their ability to re-establish photosynthetic material rapidly. The selective grazing behaviour of animals effectively changes the composition and structure of the pasture over time (Rook *et al.* 2004). In northern Australia, where paddock area may be in excess of 120km^2, proximity to water is one of the most important factors influencing selection (Tomkins *et al.* 2009).

Grazing modifies plant traits critical to the acquisition of resources by changing plant morphology (Earl 1998). The immediate impact of grazing on a plant is the reduction in leaf area (Bullock and Marriott 2000), changes to the age structure of tillers and, depending on the amount of leaf removed, potentially a reduction in the root system (Parsons and Chapman 2000). Frequent defoliation over extended periods often results in a change in the architecture of the canopy. Plants may develop prostrate growth and ultimately the dominant species and lifeforms change, perennial grasses may be replaced by annual grasses and forbs (Whalley 1994). Grazing may also affect the root biomass of plants, litter accumulation and nutrient cycling (Kemp *et al.* 1996; Rook *et al.* 2004).

The term 'grazing resistance' acknowledges that grass species respond differently to defoliation and environmental conditions (Briske 1986). Although the term is somewhat subjective, it is a useful concept to explain the relative abilities of grasses to survive and grow in a grazed environment. Morphological plasticity, polymorphism and physiological variation in response to grazing are all important mechanisms in grazing resistance. All grasses exhibit avoidance and tolerance strategies to varying degrees over time and in response to different grazing methods (Briske 1986). These strategies are of greater importance to the more desirable species which are more likely to be preferentially selected by livestock.

Repeated defoliation of desirable and palatable species decreases root biomass and the plants' ability to compete for resources relative to neighbouring plants which remain ungrazed (Bullock and Marriott 2000). A grazed plant has a higher chance of being bitten if it has been grazed previously in the growing season (O'Connor 1992): the new shoots are highly palatable, increasing preferential selection by livestock. With reduced capacity to acquire nutrients and moisture, these plants become increasingly vulnerable to moisture stress and may eventually die (Richards 1993). As the number of desirable plants in the pasture declines the grazing pressure applied on the remaining plants increases, and eventually the population declines significantly. Under any grazing regime where plants are exposed to animals for an extended period, regardless of how few animals, this process of continual weakening and subsequent decline in production of desirable plants will occur.

A range of soil types is typically found in most circumstances in extensive grazing areas and this will be reflected in the vegetation. Regardless of whether variation occurs within or between paddocks it is likely to lead to variation of species, growth rate and palatability within the landscape. The grazing method modifies the degree of defoliation of plants (Edwards *et al.* 2008). When low numbers of animals are allowed to graze relatively large areas for extended periods, the capacity for animals to preferentially graze sward components and selectively graze individual plants or plant parts is enhanced. The result is the creation of a mosaic effect in the vegetation (Kahn *et al.* 2010). Individual plants or areas will be more frequently grazed, with the high palatability of the new regrowth attracting increased attention from grazing animals, and other areas will be effectively ignored by stock. In this situation, production of those frequently grazed plants will be suboptimal due to overgrazing. Plants will remain in Phase I and those plants with high biomass (Phase III) will be increasingly less likely to be grazed and producing below potential (O'Connor 1992).

In the situation described above, the effective stocking rate on some areas of a paddock may be multiples (above and below) of the average stocking rate of the whole paddock area. Overall pasture production is reduced and livestock production will be adversely affected in both the short and long-term.

GRAZING MANAGEMENT

Grazing management is the process of controlling the movement of livestock to improve pasture growth and utilise that growth to effectively enhance the function of the ecosystem and livestock production. It is a complex process which necessarily requires incorporation into any whole farm management program or plan to achieve long-term sustainability (Donnelly 1998). The nature of the interaction between animal requirements and management to enhance plant growth and production and soil health in a variable environment means that compromises will need to be made at times.

Land managers have the capacity to exert some degree of control over four main and interrelated aspects of the grazing process, and in doing so effectively influence plant growth potential.

1. The period between grazing events, or frequency of defoliation – the recovery period.

   The effect of frequency of defoliation has been described above. Allowing adequate time for plants to recover from defoliation is critical to ensuring the persistence of desirable pasture components. With a relatively shorter recovery period the nutritional quality of plants may be enhanced and favour higher levels of animal production, although care needs to be taken to avoid plants being overgrazed. To ensure plant persistence, the effects of shorter recovery periods may be offset by the maintenance of higher post-grazing herbage mass residuals.

   There is an important distinction to be made between recovery and rest. The recovery period describes the time required for a plant to regenerate leaf area and root reserves and to recover from defoliation. The time for regrowth of shoot and roots to be initiated following defoliation is proportional to the intensity of defoliation, with roots taking longer to regenerate than leaf material (Troughton 1957).

   The rest period is the time that animals are not present in a paddock. Plant recovery depends on the occurrence of environmental conditions (rainfall and temperature) suitable for growth. Although livestock may not be grazing a paddock, in the absence of conditions conducive to growth during a given rest period, grazed plants will unlikely be adequately recovered from a previous defoliation.

2. The length of time plants are exposed to animals – the graze period.

   The graze period allocated for each paddock or subdivision will dictate the time that plants are exposed to grazing livestock, the amount of herbage mass removed from the paddock overall and from individual plants. It will also determine the degree of diet selectivity expressed by grazing animals. Ideally the graze period should be determined by the amount of available herbage mass and the desired residual herbage mass, and the amount livestock will remove to meet their nutritional requirements.

   Shorter graze periods favour high animal production since theoretically stock move onto fresh pasture more frequently and maintain a higher-quality diet. Where graze periods are long enough that animals have access to the regrowth of desirable plants that were already grazed early in that particular graze event, those plants are at risk of potential depletion of root reserves and being overgrazed.
3. The residual herbage mass post-grazing.

   The residual herbage mass that remains in an area following a graze event will significantly influence the subsequent rate of pasture growth. This issue is discussed in more detail later in this section. The timing of grazing, within the pasture growth cycle, will influence the ideal amount of residual herbage mass to leave for enhanced pasture and animal production throughout the year. A target of leaving sufficient residual herbage mass at the end of the non-growth period will optimise annual utilisation and encourage higher pasture growth rates during the following growing season. Stocking rate during the non-growth period is a major influence on annual carrying capacity in many environments.

   In general, low residual herbage mass (<1500 kg DM/ha) will usually favour animal production as the younger regrowth leaves are of higher nutritional value, although intake of beef cattle will be limited where herbage mass falls below 2000 kg DM/ha (MLA 2004). If grazed below this level, plant growth rate will be reduced and the persistence of perennial grasses will be compromised.
4. The number of animals – the stocking rate and stock density.

   The stocking rate is the number of livestock units (discussed below) that are carried on a property or paddock during an annual period, and is often described as a key driver of enterprise profitability. Regardless of the grazing regime adopted for sustainable management, stocking rate should be matched to the carrying capacity of the land. A high stocking rate in any region will be associated with relatively high pasture utilisation.

   'Stock density' is the term used for the number of livestock units grazing a paddock or parcel of land at a point in time. High stock density allows a greater degree of control over the grazing process and generally more uniform grazing of an area but it requires a higher level of management. Low stock density allows animals to be relatively more selective and is generally associated with high levels of per head production (Badgery *et al.* 2012).

There are different grazing management strategies that may be adopted, all variations on the manipulation of these four elements. The key differentiating feature is the use of measurement of herbage mass as the basis of grazing decisions. Measurement allows informed, evidence-based decisions relating to the number of stock that may be carried sustainably at any time, based on the amount of herbage mass available and the movement of the livestock across the landscape. Several of the most common approaches and a brief description of the key principles associated with each are given here.

'Continuous grazing' describes the situation where cattle are grazed on a given paddock for an indefinite period of time with control only over one aspect of grazing management (i.e. the number of animals) such that stocking rate may vary during the year. Stocking of paddocks is often based on the manager's experience and areas are usually stocked at the level of their non-growth period carrying capacity (Lodge *et al.* 2003). It is common practice in northern Australia to graze paddocks continuously at close to what is assessed as the long-term carrying capacity (Hall 2011). There is rarely any measurement of herbage mass and no effective control over the relationship between animals, plants and soils. There is little attempt to control intake, therefore pasture utilisation may be low (Lodge *et al.* 2012) and stocking rates are usually well below the environmental potential (McIvor *et al.* 2010). It is widely accepted that continuous grazing degrades land (Tothill and Gillies 1992; Norton 1998), the effects increasing in severity as the gap between stocking rate and the sustainable carrying capacity of the land increases.

'Set stocking' describes the practice of holding relatively low numbers of cattle on large paddock areas for an extended period. Several paddocks may be grazed by a mob or by different numbers or types of stock, but there is rarely any measurement of herbage mass as a basis for decisions. Movement of stock is often reactive, based on a reduction in the amount of available herbage mass or other livestock management factors, for example, paddocks may be set stocked for calving or joining or for weaned animals. Stocking rates are usually well below the environmental potential (Earl and Jones 1996). Set stocking remains the most common form of grazing management across many areas of eastern and southern Australia. Recent surveys indicate that ~50% of graziers use it as their main practice (Reeves and Thompson 2005; Trotter 2007).

'Rotational grazing' is the practice of rotating livestock through a series of paddocks; the number of paddocks may vary from two up to subdivisions in excess of 50 per mob. There are many approaches to rotational grazing, and the following approaches are often described as variations on rotational grazing in the literature. The general concept is that by allowing a period of rest between grazing events each paddock will have sufficient time to allow plants to recover from the previous graze.

Where rotational grazing is seasonal or otherwise time-based, each paddock is grazed and rested for a specific period, generally without consideration of actual pasture growth rates and differences in available herbage mass in different paddocks. The number of paddocks used in time-based rotational systems may vary as noted above (two to 50) but most often not more than 30 are used. It is not uncommon for different paddocks to have differences in soil type, vegetation and potential pasture production (both within and between), so this approach can lead to differing levels of herbage mass for the same applied rest period. Some paddocks may be overutilised and some underutilised as a result of the variable amounts of herbage mass present at the start of a graze event and remaining residual. Tothill and Gillies (1992) noted the danger of rotational grazing locking graziers into a 'mechanical pattern of utilisation'.

Rotational grazing based on plant phenology has been proposed as a method to enhance seeding and persistence of desirable species (Whalley *et al.* 1978; Dowling *et al.* 1996). When phenology is predicted from the calendar and movement of livestock is based on this premise, there is little evidence to support a significant advantage over set stocking from either an animal production or ecosystem health perspective (Kahn *et al.* 2010). The removal of stock from a paddock based on the phase of growth, immediately pre-flowering, of the target species does not generally take into account total available herbage mass in the specific area or in other paddocks.

'Strip grazing' is a form of rotational grazing usually applied in paddocks where the vegetation and paddock topography are relatively uniform. It is often implemented using temporary electric fences to subdivide and restrict animals to smaller areas while controlling graze and rest periods. The method is often, but not exclusively, applied on annual forage crops or sown pastures and may be evidence-based where several animals are allocated a specific area for a set period based on available herbage mass. Animal production targets or movement may be reactive, in response to pasture simply being eaten down to a low residual base.

'Tactical' or 'strategic grazing' may apply to a range of grazing methods, including set stocking and rotational grazing throughout the year to meet the specific animal and pasture objectives at various times (Kemp *et al.* 1996). Tactical or strategic grazing is most often applicable to individual paddocks as opposed to a whole farm grazing management program. Examples of tactical grazing include phenological-based grazing decisions (described above) or seasonal resting. Early wet season resting (Ash *et al.* 1997; O'Reagain *et al.* 2007) and rest followed by spring burning (Orr *et al.* 2005) are other tactics that may be employed for specific pasture outcomes. Planning to set aside paddocks for specific activities such as calving, weaning or finishing could be described as tactical or strategic grazing. Similarly, intensive grazing in advance of sowing a forage crop or pasture, renovating a pasture or grazing to limit seed production of a species may be described by this approach. Such actions are usually not practically applied across a whole farm simultaneously. Depending on individual circumstances, this approach to paddock management may or may not be evidence-based.

'Cell grazing' or 'time-controlled grazing' involves stock movements through several paddocks (cells). Stock numbers and movement are generally based on measures of plant growth rate and the expected required recovery period (Cook 1994) but many managers implement time-based systems. McCosker (2000) listed five principles associated with the practice of cell grazing: control rest to match plant growth, match stocking rate to carrying capacity, plan, monitor and manage the grazing, use short graze periods to increase animal production, and use maximum stock density for the minimum time.

Cell grazing is usually associated with the use of high stock density through at least 10 paddocks (cells) where each is grazed for short periods. A critical caveat is that although stock density within a cell is high, the short graze periods mean that utilisation of pasture is moderate (Norton 1998). Often this may not be the case; where animals are retained in paddocks until all herbage mass (including undesirable species) is reduced to a minimal level during a graze event, animal production is compromised and desirable sward components are often overgrazed.

In situations where stocking rate and the movement of livestock are based on measurement of herbage mass, the positive outcomes for land and livestock can be significant (Earl and Jones 1996; Alsemgeest and Alchin 2003; Orr *et al*. 2005). There are practical examples reported in the literature where management referred to as cell grazing was time-based or stock numbers were fixed, and in the absence of regular pasture monitoring animal production and/or land condition either declined or remained unchanged (Hall 2011).

Grazing cells may be established across a whole farm or within sections of an individual property. It is not uncommon for a single property to run multiple cells across the farm to cater for different classes of livestock and for those animals to move between cells.

'Planned grazing' as described by Kahn and Earl (2012) requires an understanding and measurement of herbage mass, pasture growth and animal requirements. Stocking rate is based on seasonal feed budgeting and movement of livestock is planned to ensure that an optimal amount of residual herbage mass is maintained throughout the year to enhance plant growth. Amalgamation of mobs is encouraged and, while a minimum of 15 paddocks or subdivisions is suggested, planned grazing may be applied with as few as four or five paddocks.

The ideal residual herbage mass increases throughout the growing season to ensure that there are adequate levels of herbage mass to achieve livestock production targets during the growing season and to maintain stock throughout the non-growth period, while also ensuring maintenance of maximum groundcover. Grazing in high-rainfall areas is planned to achieve a predetermined target minimum residual herbage mass which varies seasonally, down to not less than 1500 kg DM/ha at the end of the non-growing period, to ensure enhanced pasture growth in the subsequent growing season when favourable conditions return.

The key principle of planned grazing is that each individual paddock or subdivision is grazed for an appropriate period that is specific to the area, based on the starting available herbage mass, the number of livestock grazing and the desired residual. The nutritional requirements of the livestock, based on their physiological state or to achieve production targets, are factored into the plan.

'Holistic planned grazing', as described by Savory (1999), proposes the use of grazing livestock as the primary tool to regenerate land. Animal production is generally a secondary consideration, although as land condition improves potential carrying capacity and animal production also improve. With holistic planned grazing, livestock are moved in response to the plant growth and the planning is divided into two distinct periods (Butterfield *et al*. 2006).

An 'open plan' is applied during the growing season when pasture growth is rapid with recovery periods planned according to the time required for desirable species to regenerate leaf area following a graze event. During this period livestock move through paddocks relatively quickly. The actual graze period is a function of the number or paddocks and the required recovery period. A 'closed plan' takes effect when pasture growth slows or stops until the period when growth is anticipated to start. At the start of this period the available feed is assessed and stock numbers are adjusted to optimise utilisation of herbage mass during the period. The key principle is that when pasture growth slows, the movement of livestock slows (Savory 1999).

There is no recommended number of paddocks with holistic planned grazing but it is suggested that the greatest gains in improving land condition arise from the application of high stock density and increasing the number of paddocks per mob. Although the concept of holistic planned grazing was initially developed and applied in low-rainfall (brittle) environments (Savory 1999), it has been adopted in many regions throughout Australia.

'TechnoGrazing$^{\text{TM}}$' is a relatively new concept developed by Rangitikei farmer, Harry Wier, for use in bull beef operations (Charlton and Wier 2001); it has subsequently expanded to other livestock enterprises. Paddocks are precisely divided into identical sized lanes which are progressively subdivided, often using temporary single electric wires, to allow mobs to graze progressively along each lane. It allows for high-density rotational grazing with small groups of animals (other forms of grazing management involve much larger group sizes) because it can be applied on areas as low as 0.1 ha (Kahn and Kelly 2006).

The use of TechnoGrazing^{TM} is generally confined to high-rainfall zones. The cost of establishing the infrastructure will likely limit its viability in areas where annual herbage mass production is <6000 kg DM/ha. Kahn (2005) reported the cost of establishment of a Techno system on the northern tablelands of NSW to be $459/ha. A trial conducted at the site over a two-year period compared high (9.7 DSE/ha) and low (6.8 DSE/ha) stocking rates adjusted according to feed availability and residual herbage mass targets in the Techno system, with continuous grazing (5 DSE/ha). The gross margin from the high stocking rate treatment was $187/ha, which equated to a 2.5 year payback period on the investment.

The cost of infrastructure, fencing and water, is often considered a major barrier to the adoption of an alternative grazing strategy which includes increasing stock density (MacLeod and McIvor 2006). In a three-year study on the central tablelands of NSW, Badgery *et al.* (2012) reported consistent advantages in gross margin/ha in a 20-paddock flexible rotation over a four-paddock rotation and continuous grazing; however, only year 3 was significantly different. The gross margins/DSE over the period were variable and non-significant. The financial return from creating more paddocks per mob was found to be viable with an internal rate of return of 18.3–23.9%, moving from four to 14 paddocks, if no investment in infrastructure was required. However, fencing costs of $5100/km and additional water points at $3000 each made the transition a more marginal proposition.

The adoption of more intensive approaches to grazing management has been the subject of recent research in northern Australia (Ash *et al.* 1997; O'Reagain *et al.* 2007; McIvor *et al.* 2010; Hall 2011). The results have generally been inconclusive although Ash *et al.* (1997) identified that wet-season spelling may increase utilisation and O'Reagain *et al.* (2007) concluded that stocking at rates close to the long-term carrying capacity, to achieve 20–30% utilisation, was most profitable. In developing guidelines for grazing in northern Australia, McIvor *et al.* (2010) nominated several key principles: smaller paddocks resulted in an improvement in landscape use, grazing distribution was improved by manipulation of water points and management of stocking rate was vital to meet livestock production and land condition goals.

In a four-year study at nine sites throughout Queensland, Hall (2011) found no difference in ecological or production parameters measured across paddocks which were grazed continuously, rotationally grazed or cell grazed. Difference in production levels were more influenced by seasonal conditions. An issue with these types of studies is that change in vegetation is often at a rate much slower than the duration of the trial period (Kemp *et al.* 1996). An economic analysis of a site in Rockhampton, Qld, indicated a 10% marginal rate of return on investment in fencing and water infrastructure to establish a 28 paddock cell on an 8000 ha property proposing a 12.5% increase in stocking rate as a result of the development program (Hall 2011).

It is not uncommon for graziers to increase stock numbers in anticipation of increased pasture production in response to an applied input or changes in infrastructure (Burrows *et al.* 1990; Simpson *et al.* 1998). Adoption of a stocking rate strategy that is not matched to the available herbage mass (i.e. in excess of carrying capacity) will inevitably result in overgrazing of plants in the absence of favourable conditions for pasture growth. Similarly, any time-based 'systematic' approach to grazing doesn't account for the complexity and variability in the natural environment, grazing livestock and the changing needs of management (Tainton *et al.* 1996). Without adjustments to the recovery period in response to the these factors, there will undoubtedly be periods when plants will be overgrazed and pastures grazed to suboptimal residual levels. The management input into such 'systems' is often negligible, and an assumption that the absence of grazing animals from a paddock for a period will result in pasture growth is naive.

Although there is not a 'correct' grazing strategy for all situations there are several basic principles to ensure optimal animal performance, pasture production and positive outcomes for land health. The longer desirable plants are exposed to grazing animals, the higher the probability that these plants will be overgrazed. Effectively this results in a decline in root biomass and a subsequent increase in plant vulnerability to moisture and nutrient stress and to reduction of productive potential. As plants are weakened through overgrazing, the risk of death increases (Troughton 1957). As the population of desirable species decreases, increased grazing pressure is placed on the remaining individuals. Any grazing strategy which depletes the resource base cannot be considered sustainable production. Orr *et al.* (2005) highlighted the importance of this objective and the consequences for the beef industry if pasture condition is not improved.

Continuous grazing is the practice most widely used in the rangelands and northern Australia (Hall 2011) and is also still common practice in high-rainfall zones. There is general acknowledgement that pasture and rangeland have degraded (Tothill and Gillies 1992; Kemp *et al.* 1996; Ash *et al.* 1997; Peck *et al.* 2011; Lankester 2013) and that alternative approaches to grazing management are part of the solution. Reducing the number of herds for the maximum period provides more flexibility in grazing management and allows a greater area of the whole farm to be rested at any point in time. More paddocks per mob allows greater control over the grazing process and smaller paddocks allow utilisation to be more closely controlled (McIvor *et al.* 2010). Where multiple herds need to be run as part of the management program, cattle can be combined at a later date to maintain the minimum number of herds for as long as possible.

The principles of grazing management for maximising plant growth, optimising utilisation and stocking rate through the control of livestock apply in all grazed grasslands. In the rangelands and northern regions, control can be achieved by manipulation of the water source (Tothill and Gillies 1992). The location of water points is a major factor influencing the pattern of cattle grazing in northern Australia. Subdivisional fencing and increasing the number of water points will improve the distribution of grazing pressure and facilitate the ability to rest areas and improve land condition (McIvor *et al.* 2010). In central Australia, most impact from grazing occurs within a 2 km radius of the water point (Foran 1980), thus having more water points 3–4 km apart has the potential to achieve more effective utilisation of greater areas of large paddocks.

Management and resources will ultimately dictate the optimal number of paddocks per mob in any environment, but as a guide a minimum of 15 paddocks per mob increases the flexibility of grazing management and more even utilisation. The influence of paddock number on the average graze period for a range of planned recovery periods is shown in Fig. 15.6. As an example, with 15 paddocks and a 100 day planned recovery (as in periods of slow growth) the average graze period is seven days. The relatively short graze period minimises the risk of plants being repeatedly grazed and, averaged over a 12-month period, each paddock will be resting for over 90% of the time. Increasing the number of paddocks per mob provides more control over the grazing process. In any environment there is a trade-off in determining the optimum number of paddocks and paddock size, between the cost of development and the expected improvement in production and returns (McIvor *et al.* 2010).

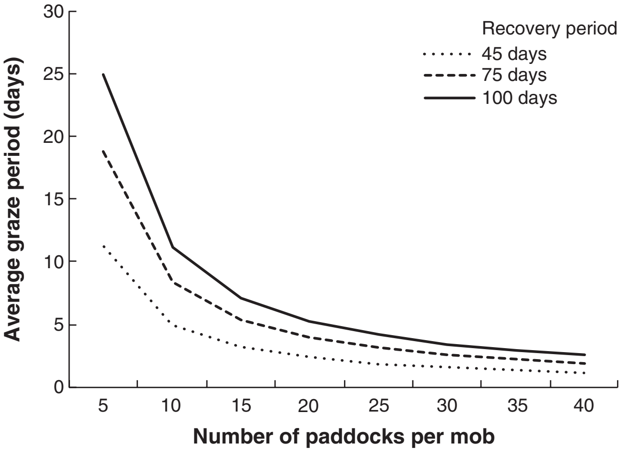


Figure 15.6: Influence of the number of paddocks per mob on the graze period for a range of recovery periods. Source: Adapted from Butterfield *et al.* (2006).

The required recovery period will be significantly influenced by the amount of residual herbage mass, through the influence on pasture growth rate following a graze event. In temperate grasslands of high-rainfall areas, a residual pasture height of at least 5 cm is equivalent to ~1500 kg DM/ha in a typical pasture. At this level of defoliation there will be minimal reduction in root biomass and the energy to drive regrowth will be provided predominantly by photosynthesis. Towards the end of the growing season, the target residual herbage mass should increase to at least 2500 kg DM/ha (dependent on stocking rate) to ensure sufficient pasture for livestock over the non-growing season and to enhance pasture growth in the next growing season.

In coastal or rangeland areas where pasture density is relatively lower or tall subtropical species dominate the pasture biomass, a higher residual pasture height of at least 10 cm will enhance production (Turner *et al.* 1993). In the arid zone where total annual herbage mass production is variable and often below the residual levels mentioned above, the principles of residual plant height and recovery time are just as important. If the herbage mass at the start of the graze period is at or below 1500 kg DM/ha, the residual target will need to be adjusted to ensure appropriate utilisation. In low-rainfall areas paddocks may be grazed only once or twice in a 12-month period as seasonal conditions dictate. Desirable plants may experience severe grazing although a sufficient recovery period will encourage adequate restoration of leaf area and root density in advance of subsequent graze periods (Troughton 1957; Greenwood and McKenzie 2001).

Regular measurement of herbage mass is essential to ensure that stocking rate does not exceed the carrying capacity of the property or individual paddocks at any time. The concepts of stocking rate and stock density are discussed below. To ensure long-term production, the allocation of the appropriate number of grazing days in each paddock must be based on the available usable herbage mass and the desired minimum residual after grazing.

Given the complexities of the grazing process, the variability of pasture growth and the demands of grazing livestock, development of a grazing plan is essential to ensure consistent optimal outcomes for pasture and livestock production. An evidence-based grazing plan based on the available herbage mass, expected pasture growth and animal requirements is necessary to ensure each paddock is grazed for the appropriate number of days. Movement of livestock can then be planned to optimise animal and pasture production and meet the needs of management in any environment.

Pasture growth rate is the main factor which influences pasture productivity and potential stocking rate. The capacity to measure herbage mass and pasture growth rate allows management to make informed decisions based on current conditions, identify the most productive areas of the property and the response of areas to applied inputs, prioritise areas for future inputs and plan appropriate stocking rates. Monitoring pasture and range condition and using that information to make informed decisions are fundamental to improving land health (McIvor *et al.* 2010)

There is a range of tools to assist in the measurement of herbage mass and to calculate pasture growth rate with sufficient accuracy and without the need for cutting, drying and weighing samples of herbage (Fig. 15.7). MLA has produced a pasture ruler to estimate herbage mass applicable for high-rainfall zones. The pasture height:density relationship is also advocated by Kahn and Earl (2005). It is a simple and reliable method to estimate herbage mass and may be easily applied by graziers in a range of environments. Tools such as the rising plate meter (Scrivner *et al.* 1986) provide a more accurate measure of spatial variation in herbage mass. A more recent innovation is the use of electronic pasture meters which rely on optical sensors and can be mounted on a quad bike; these provide instantaneous measurements (Trotter *et al.* 2010). Originally developed for nitrogen management in crops, active optical sensors which use light reflectance in the red and near-infrared to quantify green plant material are being used to measure and map pasture biomass (Trotter, pers. comm.).

Figure 15.7: Examples of pasture measurement tools. (a) The MLA pasture ruler. (b) A rising plate meter. (c) A hand-held active optical sensor.

Stocking rate and stock density

'Stocking rate' is defined as the number of livestock expressed as dry sheep equivalents (DSE) carried on an area of land. It is usually calculated over a 12-month period and relates to either the whole property, sections of a property, groups of paddocks or individual paddocks. Stocking rate is commonly considered to be the major influence on plant and animal production (Hall 2011) and one of the main drivers of ecological health and sustainability (Donnelly 1998). A primary principle of sound grazing management to enhance the condition of the resource base is to match stocking rate to the carrying capacity of the land. The challenge of consistently applying the appropriate stocking rate has been identified as a major management issue for the rangelands (Stafford Smith *et al*. 2007; Lankester 2013). Various methods used to calculate stocking rate are summarised below.

In southern Australia, DSE (McDonald and Orchard 1985) are used as the base unit to estimate the metabolisable energy required to support maintenance and growth of sheep and beef cattle. DSE are based on multiples of the metabolisable energy (ME) required to support a mature 50 kg wether or dry (non-reproductive) ewe to maintain its bodyweight (8 MJ ME and DSE = 1). For convenience in feed budgeting, 1 DSE represents the (approximate) consumption of 1 kg dry matter of pasture. This accounts for the varying digestibility of pasture associated with different growth rates and energy requirements of livestock.

Other measures are used to express stocking rate in different regions. A common measure applied in northern Australia is the adult equivalent (AE), which represents a dry cow or a steer maintaining a liveweight of 450 kg. One livestock unit (LSU) represents a 450 kg steer maintaining weight and is equivalent to 8 DSE. Standard animal unit (SAU) is another term, with one SAU representing a dry (non-reproductive) cow. A 500 kg cow or 1 SAU would equate to 9 DSE. The number of breeding cows per unit area is often used to express stocking rate, particularly in coastal grazing regions. The annual average requirement of a breeding cow is 15 DSE.

All methods are valid indicators of the number of livestock carried, expressed in a common unit. For the purposes of matching livestock feed requirements with herbage mass (i.e. feed budgeting), DSE is the most convenient and mathematically simple approach because it places both livestock demand and feed availability in the same units (1 DSE = 1 kg DM). This is of particular importance in the calculation of stock density and the appropriate number of days a given herd should remain in a paddock.

'Stock density' refers to the number of DSE grazing an allocated area or paddock on any day. It defines the amount of herbage mass those animals will remove each day based on their physiological state, growth rate and associated nutritional requirements. Stock density is expressed as DSE/ha (kg of pasture dry weight consumed per ha).

Once the appropriate stocking rate has been determined, stock density is perhaps the most important element of grazing management in terms of control over the grazing process. At high stock densities (500–1000 DSE/ha or more), the manager has a high degree of control over the interaction between grazing livestock and the pasture. Consistently achieving such levels of stock density requires a relatively large number of paddocks or subdivisions, generally 50 or more per mob.

The benefits associated with the control over the grazing process achieved with high stock density include a more even distribution of manure and urine, and a more even graze with more plants either bitten or otherwise physically affected (Savory 1999). Residual herbage mass targets may be more successfully achieved and more organic matter is left in contact with the soil.

Grazing livestock at high density requires a high level of management expertise, regular monitoring of pasture herbage mass and planning to achieve the desired animal production targets and simultaneously enhance the condition of the resource base. The rewards can be significant, with many cattle producers reportedly achieving 100% increases in carrying capacity within five years. Managers employing high stock densities usually associate it with some form of planned grazing due to the level of planning and monitoring required to achieve these results.

A common criticism of high-density grazing is that individual animal performance declines. While individual or per head production may be lower, per hectare production may increase (Badgery *et al*. 2012) and this factor is the key driver of profitability in commercial beef enterprises (Chapter 20). Other problems may initially arise with stock handling and forcing animals between paddocks but cattle quickly become accustomed to frequent moves and the reward of fresh pasture, and move quickly to the next area.

Published reports on the impact of stock density on land condition are absent from the literature; it is an area that warrants investigation. The general guidelines on the effects of differing levels of stock density presented here have been based on the experience of the author. In higher-rainfall zones (>550 mm) a minimum stock density of 200 DSE/ha is recommended to achieve change in pasture production, enhance the species composition and gain soil health benefits. At stock densities below this level, the rate of change will likely be slower and more often the recovery period is the dominant factor in creating landscape change. Below 100 DSE/ha it is more difficult to effectively control the grazing process;

inevitably, evidence of selective grazing will appear in paddocks and overgrazing of plants may occur. In this situation, graze periods will often extend beyond seven days which, in periods of rapid pasture growth, will result in many desirable plants being defoliated a second time and potentially overgrazed.

At low stock density (<50 DSE/ha), where few animals graze large areas for extended periods, it is inevitable that the condition of the pasture resource will eventually decline in the absence of inputs. Pasture production will be suboptimal as some areas of a paddock will be overutilised and plants overgrazed and other areas will be underutilised and plants ignored (Earl and Jones 1996). Generally high levels of inputs will be required to maintain pasture and animal production.

The same principles apply in rangelands and lower-rainfall regions (<550 mm) although the logistics and economics of fencing and watering animals to achieve high density are often not feasible. More even utilisation or zones of high animal impact can be achieved with strategic placement of supplements or manipulation of watering points (McIvor *et al*. 2010; Probo *et al*. 2013). The potential level of stock density will depend on the resources available. In rangelands and other areas where low stock density is applied, it is likely that pasture rest (allowing paddocks, particularly the desirable plants within a paddock, sufficient time to recover from a graze event) will be the primary driver of change (O'Reagain *et al*. 2007). Property development, including fencing to reduce paddock size and to reduce the distance between water points, can improve the distribution of grazing livestock and increase the area of a paddock that will be utilised (McIvor *et al*. 2010).

Stocking rate has long been considered a key determinant of pasture growth rate and land health. However, Kahn and Earl (2005a) failed to identify any correlation between pasture growth rate and stocking rate over a 10-month period across 30 paddock sites on the northern tablelands of NSW. It is important to note that in each instance the management goals for each paddock varied; they were not necessarily managed for maximum production or optimal stocking rate. However, the data provide some counter evidence to the common assumption that stocking rate is the primary influence on pasture growth.

While it is critical to ensure stocking rate does not exceed the carrying capacity of an area, and utilisation of herbage mass is a function of stocking rate, it is indicated that utilisation has a greater influence on long-term potential pasture productivity (Kahn and Earl 2005a). In northern Australia, Tomkins *et al*. (2009) suggested that the spatial distribution of livestock may be more important than stocking rate in influencing pasture utilisation. The time plants are exposed to livestock and the subsequent period of recovery from grazing may be of relatively more importance in influencing pasture growth than the number of livestock carried at any point in time. These data support the suggestion by Hyder *et al*. (2004) that more effective utilisation can increase farm profitability.

It is incongruous that so few scientific studies of grazing management have identified significant differences between grazing methods when many beef cattle producers have recorded large changes in landscape health and productivity following adoption of planned grazing with high stock density. Norton (1998) identified the divergence between researchers and producers in the benefits of rotational grazing strategies in livestock production and profitability. One explanation may be that the strict experimental guidelines associated with most grazing studies cannot account for the flexibility of management which is essential for graziers to be able to adequately respond to environmental cues (Pratley and Virgona 2010). Often only a small number of paddocks are used (usually four to eight) in rotational grazing trials, and relatively small paddock areas (Norton 1998).

Kemp *et al*. (1996) acknowledged that the slow rate of change in pasture composition and change in other landscape elements often exceeds the duration of many comparative grazing studies. Such research requires a high level of resources, is often location-specific, usually limited in the variables which can be controlled to any degree and must be conducted over a long term (Stafford Smith 1996; Hall 2011). The need for flexibility in grazing management to respond to environmental variation, by adjusting livestock movement and numbers in response to measured changes in pasture growth and available herbage mass, is critical in attaining positive landscape change, animal production and enterprise profitability.

PASTURE UTILISATION

'Pasture utilisation' refers to the proportion of herbage mass grown in a period and consumed by livestock (Kahn and Earl 2005; Stone *et al*. 2008). The percentage of the herbage mass that is utilised within an annual growing cycle is one of the most important factors influencing the productive potential of a pasture in the short and long terms. The beef cattle industry estimates that the annual utilisation rate of pastures is 30–40% (MLA 2004), typically 25–30% in southern regions (Lodge *et al.* 2012). Effective management of utilisation requires a degree of control over the grazing process.

The appropriate sustainable rate of utilisation depends on the total annual herbage mass produced. In high-rainfall zones, where annual production is >6000 kg DM/ha, up to 60% allocated to livestock is considered a sustainable level of utilisation that will enhance the long-term productive potential of the pasture (Jones 2000; Kahn and Earl 2005a). Below 6000 kg DM/ha, annual pasture production utilisation of not more than 50% should be planned to enhance potential production. It may be possible to achieve sustainable outcomes with up to 70% utilisation (or more) where the total annual production exceeds 10 000 kg DM/ha. The reason for increasing utilisation with pasture production relates to the quantity of pasture not utilised by livestock. For example, utilisation of 60% with annual production of 6000 kg DM/ha leaves an annual residual of 2400 kg DM/ha (40%) unutilised. A higher utilisation of 70% with annual production of 10 000 kg DM/ha leaves a greater amount (3000 kg DM/ha). The first stage in using utilisation to inform decisions aimed to increase production is the measurement of pasture growth and herbage mass.

In rangeland areas where average annual herbage mass production is relatively low, much lower levels of utilisation are recommended. Wilson *et al.* (1990) suggested utilisation of 20% in mulga country around Charleville where annual herbage mass production was estimated at 500 kg DM/ha, and 30% has been identified as appropriate for Mitchell grasslands (Johnston *et al.* 1996; Orr and Phelps 2013). A range of utilisation rates from 13–52% has been reported as applicable in the rangelands and northern Australia (Orr 2005), depending on annual production. The sustainable utilisation was identified as 30%; higher rates resulted in a decline in pasture herbage mass and plant density, an increase in undesirable species and a decline in per head animal production. For tropical tallgrass rangelands Ash *et al.* (1997) recommended not more than 25% utilisation in areas of high or moderate fertility, reducing to 15% on low-fertility soils in the monsoon zone in the north and north-west. The sustainable utilisation rate will depend on the annual herbage mass production and will vary from year to year depending on seasonal conditions.

Management needs to be flexible enough to adapt to the environmental conditions. Control of utilisation in rangelands and northern Australia is primarily achieved through adjustments in stocking rate. It is not uncommon for graziers to apply stock numbers based on their experience of long-term carrying capacity (Johnston *et al.* 1996; Hall 2011), however, in low-rainfall years even this conservative approach may result in excessive utilisation and contribute to decline in range condition (McKeon *et al.* 2009). The concept of a single optimum stocking rate is applicable only where the annual seasonal variability is small (Stafford Smith 1996) – a rare scenario in most regions of Australia's grazing lands.

In the northern areas, where the median property area is >36 000 ha in north-west Queensland, >304 200 ha in the Northern Territory and 286 200 in northern Western Australia (Bortolussi *et al.* 2005a), frequent adjustments in stocking rate are not feasible. It is not uncommon for cattle numbers to be adjusted once annually, at the end of the wet season. However, O'Reagain *et al.* (2007) proposed an additional time for stocking rate assessment and potential adjustment. They recommended a dry-season feed budget based assessment in May–June to set stocking rates for the year based on dry standing feed available and expected wet season growth, and a second point in the late dry–early wet using seasonal forecasts and actual current pasture availability and animal performance. The reasoning included ensuring maximum groundcover to the start of the wet, measuring progress against expectations, matching stocking rate to available feed and avoiding excessive defoliation during drought and lower-than-average wet seasons. In such a variable environment, increased monitoring to make more informed decisions and planning the use of available feed can only be beneficial (McIvor *et al.* 2010).

The choice of grazing management strategy will have a significant influence on the degree of control over the utilisation of plants and pastures as a whole (Edwards *et al.* 2008). In high-rainfall zones, the level of control over pasture utilisation is most strongly influenced by stock density. The higher the stock density, the more control management can exert on all elements of the grazing process (Lemaire and Chapman 1996). Since high stock density is most often associated with short graze periods and high paddock numbers, the level of consumption of herbage mass can be controlled with a greater degree of certainty.

While it is not possible to control the height to which individual plants are grazed during a specific grazing event, the severity of defoliation may be offset through management of the frequency of grazing (Parsons and Chapman 2000). For this reason the most desirable plants

– those that experience the most severe defoliation in a graze event – must be the key indicators used to determine the recovery required. The most palatable species in the sward are those primarily responsible for livestock production.

As utilisation is a function of pasture growth rate over a defined period, the appropriate seasonal utilisation rate will vary significantly. In the high-rainfall zone, when pasture growth is at its seasonal peak, utilisation rates ideally will be relatively low, around 30–40% of pasture growth being allocated to livestock. During periods of slow or no pasture growth, livestock will be consuming pasture at a level in excess of growth and utilisation will be inevitably more than 100% (Kahn and Earl 2005). At other times of the year and depending on pasture growth rate, utilisation rate should usually be 40–60%.

Remembering that severity and frequency of defoliation are compensatory, in temperate regions the key paddock production indicator of pasture utilisation is the annual measure. Adverse effects of severe grazing at any time may be alleviated by allowing an extended period in which plants can recover (Parsons and Chapman 2000). If the annual percentage utilisation exceeds the appropriate level for a given measure of annual herbage mass production, it is most likely that a high proportion of plants will have experienced overgrazing and their immediate and future production potential will be compromised.

PASTURE MANAGEMENT

Soil is the foundation of a healthy pasture and pasture management is essentially the management of plants to improve soil health, increase pasture growth and improve animal production. Management of the above-ground plant parts is the most effective method of enhancing the function of below-ground processes. The influence of grazing animals on the plant–soil interaction is perhaps the most important feedback loop in grassland ecosystems (Huntly 1995).

Soil processes

Perennial plant roots are the most effective and cheapest soil conditioning agents available to graziers. Grass roots are a primary source of soil carbon: the zone immediately surrounding the plant roots (the rhizosphere) supports the majority of the active biology in a soil and microorganisms account for up to 80% of the energy expended in a grassland (Hutchinson and King 1982). The adventitious roots have the capacity to penetrate deep into the soil profile, effectively improving structure and porosity (Killham 1994). Grazing and managing plant recovery to increase root density and depth will enhance plant and pasture growth.

Although active soil management is difficult, modification of soil conditions by the grazier is most easily achieved through management of the above-ground plant parts. Maximising photosynthesis is the first step in the process to encourage root development and pasture growth. Maintaining pastures between 5 cm (post-grazing) and 20 cm (pregrazing) average height (1500–4000 kg DM/ha) in high-rainfall areas and 10–40 cm in coastal and rangeland regions will enhance root density and depth and ensure optimal plant growth (Parsons and Chapman 2000; Lee *et al*. 2008).

Grazing management affects soil biological, physical and chemical processes. In addition to effects on root volume, depth and density defoliation stimulates the release of exudates from the roots. Organic compounds in root exudates are continuously metabolised by rhizosphere microorganisms (Neumann and Romheld 2000). Grazing stimulates the exudation of carbon from roots into the soil; it is quickly assimilated into microbial biomass, effectively enhancing nutrient flow and promoting plant growth (Hamilton and Frank 2001).

Soil carbon, organic matter and humus

Soil carbon is the key to a healthy soil and is a primary component of soil organic matter and humus (Young *et al*. 2005). In grasslands the pasture plants, through leaf and root residue and exudates, are the primary source of available carbon for soil biota (Gupta and Ryder 2003). It is estimated that since European settlement carbon levels in Australian soils have declined by 50–80% (Dalal *et al*. 2004) as a result of changing land use including land clearing, cultivation and overgrazing (Young *et al*. 2005). Soils in temperate regions typically record carbon levels (soil depth 0–10 cm) of 2–3% depending on soil type. Cultivated soils on the slopes and those in arid zones often contain <1% carbon (Johnston *et al*. 1996) and in the tropical rangelands soils also average only around 1% carbon (Pringle *et al*. 2011).

The actual amount of soil carbon present in a soil is determined by the balance of inputs from primary production of vegetation (live and litter components) and the rate of decomposition of organic matter (Grace *et al*. 2006). As biomass of vegetation increases, the potential to raise soil carbon levels increases. Grazing management, through its influence on root biomass and plant growth, has a significant influence on carbon availability in soil (Gupta and Ryder 2003).

The potential amount of carbon (C) in a given soil is dictated by rainfall, temperature, vegetation and soil type, primarily through the influence of the environment on plant growth and soil biology (Young *et al.* 2005). Baldock (2008) described the four main types of carbon that constitute soil carbon, and their key functions:

- plant residues >2 mm in and on the soil surface – a primary source of microbial energy. Primarily derived from roots, these are the largest contributor to the soil carbon pool;
- particulate C – essentially plant pieces <2mm, important for soil structure;
- humus – the product of microbial decomposition, providing an important source of nutrient and increasing the water-holding capacity of soil;
- recalcitrant C – the biologically stable fraction that may be chemically or physically protected, typically occurring as charcoal.

This list essentially describes the insoluble forms of soil carbon which make up 90% of the total organic carbon pool. Soluble carbon sources are those arising from root exudates and exudates from soil biota, and biomass carbon derived from soil organisms (Killham 1994). The higher the biomass of soil carbon, the higher the level of biology that may be supported in the soil (Guitian and Bardgett 2000).

Soil carbon is described as labile or non-labile. Labile carbon is the fraction that is most readily decomposed by soil microorganisms. The amount of labile carbon in the soil has an important effect on soil biological activities such as mineralisation of nutrients, generation of soil structure and specific enzyme activities (Murphy *et al.* 2011). The labile fraction has a greater influence on the structure and function of microbial communities than the total soil carbon pool.

With sound grazing management, the carbon cycle in soils will be a positive feedback system. Pasture production is enhanced by soil biological processes and optimal shoot and root growth which, in conjunction with soil water, provide the primary resources for microbial growth (Gupta and Ryder 2003). Greater root density and depth increase porosity and decrease bulk density of the soil, further enhancing conditions for plant growth and microbial populations. The soils supporting rangeland and grazed grasslands have a vast capacity to store carbon (Jones 2007; Howden *et al.* 2008; Ferguson 2012). The realisation of this potential will be influenced by grazing management but, depending on the environment, progress may be measured over many years.

Soil organic matter on average contains ~58% carbon (Edwards *et al.* 1999). Leaf material and roots provide the

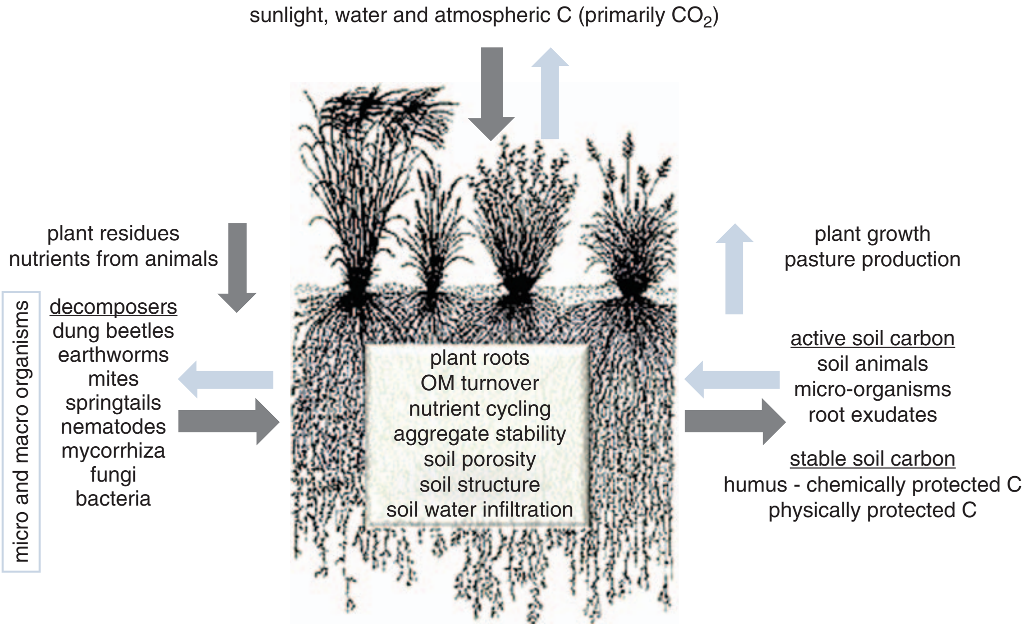


Figure 15.8: Conceptual model of the key inputs, processes and outputs in effective carbon cycling.
Source: Adapted from information from Killham (1994); Gupta and Ryder (2003).

major source of organic matter input to the soil, after root exudates and microorganisms. Constant addition to the organic matter pool is necessary for agricultural practices to be considered sustainable (Crawford *et al*. 1996). Turnover of the plant material by other living components such as soil micro- and macroorganisms is an essential part of the process of increasing the total organic matter pool (Baldock and Skjemstad 1999). The process is enhanced by grazing which may increase the turnover of root material and accelerate the release of root exudates into the soil (Singh *et al*. 1991; Hamilton and Frank 2001) as well as the return of leaf litter to the soil surface. Excessive defoliation reduces root biomass and microbial carbon, effectively reducing the total organic matter pool (Troughton 1957; Medina-Roldan and Bardgett 2011).

The end product of the turnover is humus, a relatively stable component of the carbon pool which may be physically or chemically protected (Killham 1994). Humus contributes to soil structural stability, water-holding capacity and nutrient availability (Baldock 2011) and has the potential to hold up to 20 times its weight in water (Paynter 2006). An increase of 1% humus in topsoil can result in a four-fold increase in water-holding capacity (Morris 2004). Figure 15.8 illustrates the key contributors to the carbon cycle and the outcomes from the effective function of the process.

Nutrient cycling

The rate of nutrient cycling in soil is driven by biological activity, the level of which is strongly influenced by soil moisture and soil organic matter. The quality of the plant material returned to the soil is also an important component in nutrient cycling and the rate of turnover (Murphy *et al*. 2011). Just as the quality of pasture is critical to ruminant nutrition, so the quality of plant material returned to the soil is critical to the activity of soil microbes.

Increasing pasture quality and plant growth stimulates below-ground processes, including root growth and biological activity which will promote mineralisation (Guitian and Bardgett 2000). Although the extent varies between species, defoliation stimulates biological activity via the release of root exudates such as sugars, amino acids, carboxylates and phenolics which provide a source of soluble carbon for microbial growth and enhance nutrient mobilisation in the soil solution (Neumann and Romheld 2000).

The specific role of *Rhizobium* bacteria and legumes in nitrogen fixation is the most widely documented example of direct relationship between soil biota and plant roots (Killham 1994; Gupta and Ryder 2003). Rhizobia growth is enhanced where a flow of carbon from plant roots exists in the rhizosphere. The other primary plant–microbe relationship is that of mycorrhizal fungi. The relationship of mycorrhiza with plant roots effectively extends the capacity of the host plant to access nutrients and moisture (Bolan 1991). The absorptive capacity of the fungal hyphae is increased up to 10 times that of plant root hairs and ~100 times greater than roots (Jones 2009).

There are different forms of mycorrhizal associations with the majority of plant species, although the most widely reported is the vesicular arbuscular mycorrhiza (VAM) (Killham 1994). In addition to increasing the soil exploration capacity, mycorrhizal fungi have been shown to increase the solubilisation and uptake of poorly soluble phosphorus sources (Bolan 1991). The available nutrient concentration of soil significantly influences mycorrhizal development, and high levels of available nitrogen and phosphorus often suppress fungal activity.

Soil macrofauna such as earthworms and dung beetles accelerate the decomposition process, nutrient turnover and soil fertility (Doube 2003). Through their ingestion and excretion of organic material, earthworms increase nutrient availability in a form more suitable for plant uptake and enhance soil structure and water infiltration (Macgregor 1994). Little is known of the activity of soil macrofauna in northern Australia, but in southern areas they have a significant role in enhancing pasture growth (Baker 2003). In high-rainfall zones, compaction due to the low density and depth of plant roots as a result of overstocking reduces earthworm numbers and activity.

Effective pasture management is a positive feedback system. Any management action to enhance plant rooting depth and soil conditions will improve pasture growth which, when utilised appropriately, increases the amount and quality of organic material returned to the soil, which builds soil fertility and plant growth. Making optimal use of the soil food web and natural nutrient cycling processes may significantly reduce the need for addition of fertiliser in many situations.

Water use efficiency

Soil moisture content is the primary limitation to soil biological activity (Gupta and Ryder 2003; Murphy *et al*. 2011). It is not possible to adequately consider soil organic carbon and nutrient cycling in isolation from the influence of soil moisture. The water-holding capacity of any soil is a function of porosity or bulk density. The level of porosity in soil will be influenced by the volume and density of plant root material present. Maintaining temperate perennial grass plants at a minimum height of 5 cm (1500 kg DM/ha) will minimise disturbance to the root system and ensure optimal root surface area is retained to support soil biota. Soil degradation and decline in soil organic matter occur when pasture biomass is reduced below critical thresholds (Morley and Daniel 1992).

Rainfall is a primary factor influencing pasture growth rate, and the efficiency of water use by plants is a key outcome of pasture management. Water use efficiency (WUE) is defined as the biomass of pasture produced (kg DM/ha) per millimetre of rainfall received (Kahn and Earl 2005). WUE may be significantly altered by grazing management through the influence of animals on pasture plants and root density but will also change seasonally due to the range of other factors that influence pasture growth (Table 15.1). Although primarily a function of soil conditions, WUE is also influenced by the timing of rainfall and its distribution throughout the year.

Increased depth and density of perennial plant roots and the associated biology serve to enhance soil structure. As roots turnover and die back, channels created within the soil profile increase porosity and reduce the bulk density. The activity and movement of soil macroorganisms also aerate the profile, effectively increasing the soil water-holding capacity. These features of the soil are all sensitive to the management of grazing livestock. Table 15.3 provides a theoretical example of the relationship between WUE and annual herbage mass production in a 700 mm rainfall environment, from a low-level WUE of 6 kg DM/ha/mm to a higher level of 12 kg DM/ha/mm. It highlights the potential gains in annual herbage mass production through the enhancement of soil processes which may be achieved through appropriate grazing management.

Table 15.3: Theoretical relationship between WUE, annual herbage mass production and the conversion efficiency of rainfall into herbage water content in a 700 mm rainfall environment

WUE (kg DM/ha/mm)	Herbage dry wt (kg DM/ha/yr)	Herbage fresh wt (kg fresh wt/ha/yr)	Herbage water (L/ha/yr)	Conversion (rain to herbage, %)
6	4200	16 800	12 600	0.18
8	5600	22 400	16 800	0.24
10	7000	28 000	21 000	0.30
12	8400	33 600	25 200	0.36

700 mm annual rainfall = 7 000 000 L/ha.
Assumed average dry matter herbage = 25%.
Source: Kahn and Earl (2012).

Soil compaction is one of the primary factors limiting plant growth, as reduced root biomass limits the carbon food source to soil biology (Gupta and Ryder 2003). Where plants are frequently grazed to a level that impedes root development, the absence of root material and biological activity reduces porosity and results in the development of a zone of compaction usually 5–15 cm below the soil surface (Earl 1998). While most root biomass is concentrated in the top layers of soil, many perennial grasses have the capacity for rooting depth in excess of 100 cm (Troughton 1957). The presence of deep-rooted perennial plants will enhance the water-holding capacity of the soil and plants' ability to access water, so plant growth may continue longer in times of moisture stress.

Pasture species diversity

The main mechanism by which pasture species diversity is influenced by grazing management is through the effect on sward structure primarily as a result of diet selection (Rook *et al*. 2004). The state and transition model presented by Westoby *et al*. (1989) provided several examples of changes between vegetation states and species diversity in response to management and climate in the temperate Riverina region and semi-arid grassy woodlands of eastern Australia.

The value of biodiversity in conferring resilience on pasture systems is increasingly acknowledged (Sayer and Cassman 2013). Species diversity provides stability (i.e. the ability to resist change) to grasslands (Bolger and Garden 1998). A diversity of species with different growth cycles may effectively extend the growth period of a pasture (Sanford *et al*. 2005). All species have specific environmental parameters within which growth is optimal. The 'rolling' phenologies in a diverse pasture provide a sequence of peak production levels throughout the growing season, resulting in a higher-quality feed base over a longer period (Norton 1998). Between years and seasons, environmental conditions differ and they will often favour the growth of a species or a suite of species over others. Given a certain level of soil fertility, a diversity of species and functional groups (perennial and annual grasses, forbs, legumes) within a pasture will increase the likelihood of maximising production regardless of seasonal variation (Sanford *et al*. 2005).

The presence of a range of perennial grass species, forbs and legumes contributes to diversity in the diet of cattle (Edwards *et al*. 2008). The value of legumes in increasing the pasture quality and digestibility has been well documented. Broadleaf plants, or forbs, tend to have a higher concentration of minerals than most perennial grasses and at levels up to 10–15% of the available herbage mass can have a positive influence on pasture production and the quality of animal intake (MLA 2004; Kahn and Earl 2005).

A diversity of pasture species will result in a diversity of root structure and architecture within the soil. Different species will release a different suite of exudates in response to defoliation, which will support a greater diversity of soil biota, further enhancing soil biodiversity (Paynter 2006).

NATIVE PASTURE

Native pastures and rangelands dominated by native species occupy over 90% of the grazing land of Australia (Whalley and Belloti 1997). Woodland and native pastures in northern areas of Australia are the primary forage resource for the majority of beef cattle (Hall *et al.* 1998; Orr 2005; Quirk 2010). In the tablelands regions of NSW most pastures are predominantly native-based although the composition of some paddocks may include a proportion of sown species. Native and natural pastures and rangelands have a significant role in the beef cattle industry, the area of sown pasture at 30 million ha nationally (6% of the grazed land area; Anon 1993) being relatively small by comparison (Fig. 15.9).

In Queensland, black speargrass (*Heteropogon contortus*) is the most important native grass species in terms of animal production and, in combination with pastures of the box ironbark, woodlands (*Aristida-Bothriochloa*) and Mitchell grasslands (*Astrebla* spp.) contribute to the greatest area of grassland (Burrows *et al.* 1990; Orr 2005). The majority of native pastures in northern Australia occur in woodland (DERM 2011) and they have an important role in the grazing industry, although the deterioration of pastures is widely recognised (Tothill and Gillies 1992; Orr *et al.* 2005).

Symptoms of pasture degradation include loss of desirable perennial grass species, an increase in undesirable species, declining soil organic matter and fertility, increasing bare ground, increasing prevalence of weeds, and reduced pasture growth and annual herbage mass production, which results in lower animal production

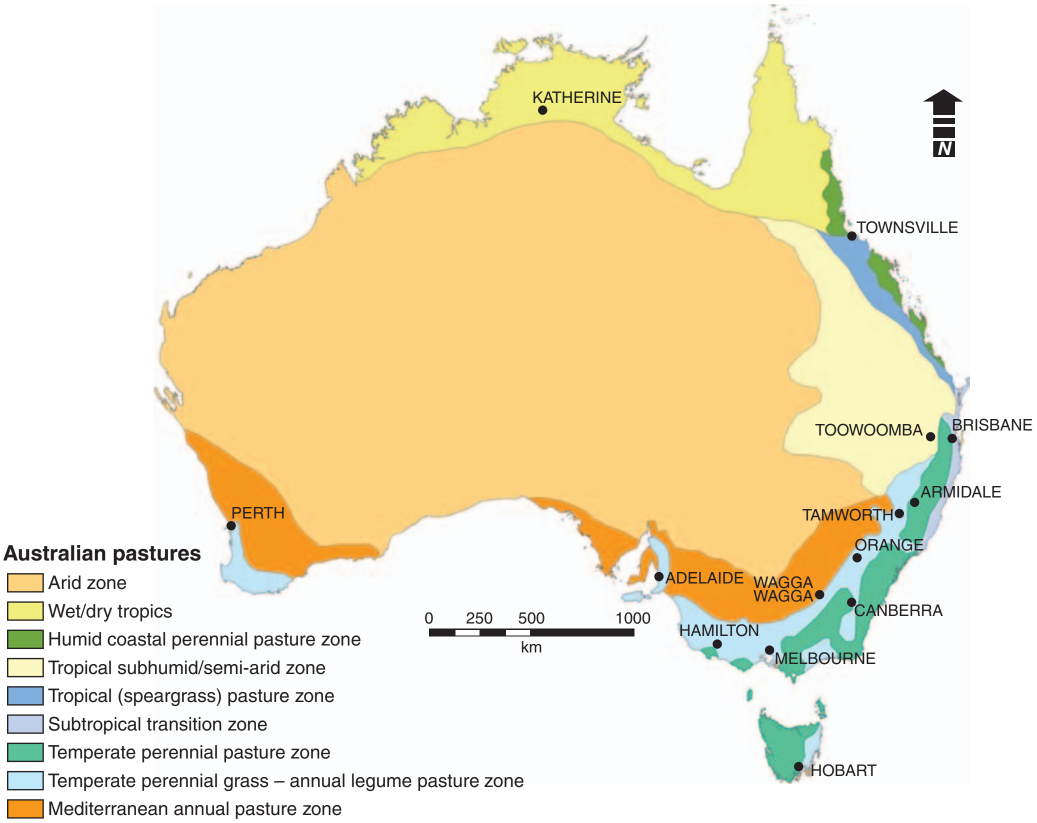


Figure 15.9: Pasture zones of Australia. Source: Wolfe (2010).

(Tothill and Gillies 1992; Stafford Smith *et al.* 2007; Peck *et al.* 2011). These symptoms are not confined to the northern regions; a similar suite of symptoms have been described by Kemp *et al.* (1996) as affecting temperate pastures. The most common cause of the deterioration in pasture productivity and land condition is inappropriate management of grazing livestock exacerbated by extended dry periods.

Since the report of Tothill and Gillies (1992) and through much of this century, most of northern Australia has experienced sustained periods of drought but cattle numbers have continued to increase (Hunt *et al.* 2012), thus compromising post-drought recovery. The level of pasture deterioration has become a major issue for the beef industry (Kemp *et al.* 1996; Orr *et al.* 2005). There appears a general consensus that native pastures are in poor condition and that continued unsustainable use is a major concern for the viability of northern beef production. Improved grazing management is seen as having an important role in reversing the trend and in recent years there has been significant investment by organisations such as MLA in research into grazing management options for the northern regions (McIvor *et al.* 2010; Hall 2011).

In the high-rainfall zones, the addition of legumes into native and naturalised pastures has been widely practised to improve the nutritive value of native pastures. The introduction of subclover (*Trifolium subterraneum*) and the associated use of superphosphate in the 1950s transformed the productive potential of native pastures in tablelands regions and southern Australia (Wolfe 2010). In northern Australia, stylo (*Stylosanthes* spp.) and leucaena are the most widespread legumes introduced into native pastures (Quirk 2010). The increased use of legumes in native pasture may offer an opportunity to reverse the deterioration of native pastures in northern regions (Peck *et al.* 2011).

An additional issue specific to northern Australia is the management of the tree–grass balance of native woodlands. The balance between trees and shrubs and pasture grasses may affect land condition in different ways. While it is acknowledged that trees compete with pasture for nutrients and moisture and that they limit light to grasses, they also provide shelter for livestock and habitat for wildlife and may enhance pasture quality in situations of low soil fertility (DERM 2011). Continuous grazing of the native grass understorey reduces herbage mass and soil surface cover, reducing fuel load and increasing the potential for greater dominance of woody species to the detriment of pasture production and quality. Fire management, in combination with grazing, is critical in maintaining the balance (Child *et al.* 2010, Scott *et al.* 2010).

Native grass species are well adapted to extended periods of moisture stress and survive on soils with low inherent fertility (Lodge and Whalley 1989). They are less adapted to frequent defoliation by grazing livestock associated with continuous grazing or extended periods exposed to animals, which has been the traditional form of management applied in rangeland areas (Hall 2011). As a result, the populations of many of the most palatable and productive native grasses have declined or been eliminated from pastures, and landscape health and productivity have simultaneously declined (Kemp *et al.* 1996; Ash *et al.* 1997; Hall *et al.* 1998).

In contrast, only relatively recently has the productive potential of native pastures in high-rainfall areas been acknowledged and reported. In a production trial at Glen Innes comparing four native species with phalaris and fescue, all native species recorded greater annual herbage mass yield (kg DM/ha) than fescue and were comparable to the yield of phalaris (Simpson and Langford 1996). In earlier trials, Robinson and Archer (1988) found that a range of native species compared favourably to introduced species in terms of herbage mass production and quality when grown under similar conditions.

In a pot experiment comparing the effects of defoliation frequency on the production of seven native species and phalaris (seed from all species was harvested from field sites), extending the defoliation interval from two to eight weeks over a period of 12 months significantly increased the total dry matter production of all native species (Earl 1998). Plants were cut to 3 cm height at two-, four- and eight-weekly intervals and an additional treatment was uncut for the period. Phalaris was the only species where total herbage mass was unaffected by defoliation interval. When the defoliation interval increased from two to four weeks, the total herbage mass produced across all native species increased by 98%. Extending the defoliation interval to eight weeks resulted in an additional 50% gain in cumulative herbage mass over the 12-month period (Fig. 15.10).

A more significant result recorded across all species was the effect of defoliation interval on total root biomass over the period. All species cut at four-weekly intervals recorded double the root biomass of those cut fortnightly, and plants cut at eight-weekly intervals recorded root biomass twice that of the plants cut at four-weekly intervals. An example of the effect of defoliation frequency on

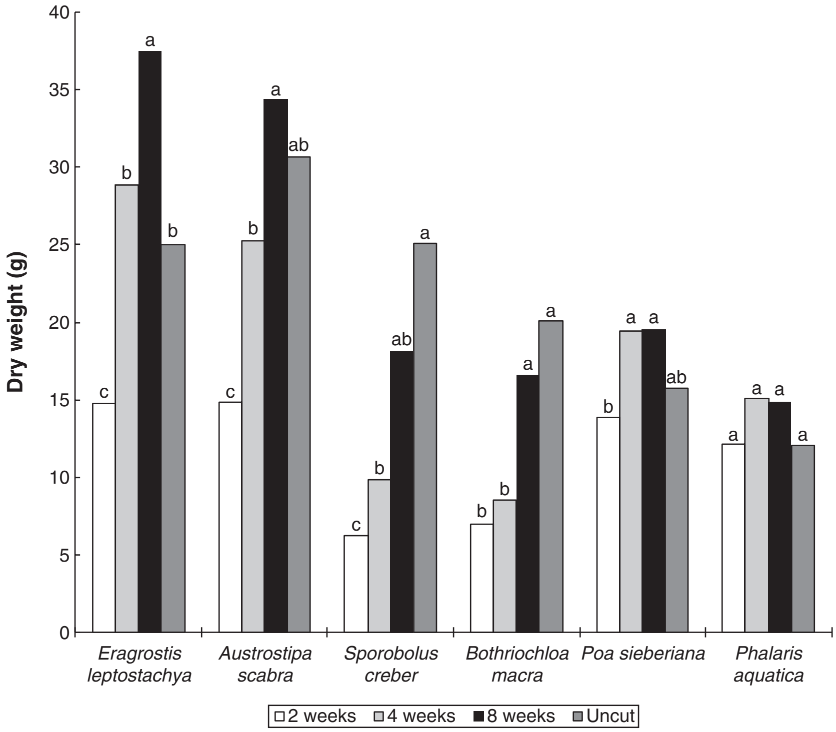


Figure 15.10: Mean cumulative herbage mass production (g/plant) of six grass species cut to 3 cm at two-, four- and eight-week intervals and uncut over a 12-month period. Within-species bars sharing the same letter are not significantly different ($P < 0.05$). Source: Earl (1998).

the roots of the native paddock lovegrass is shown in Fig. 15.11. The key conclusion from the trial was that native species require a relatively longer recovery period following defoliation to achieve their productive potential and maintain optimal levels of root biomass to enhance persistence. Similar results were reported by Nie *et al.* (2009) with seven native grass species cut to heights of 2 cm, 5 cm and 10 cm at three- and five-week intervals. Cutting at 10 cm and 5 cm increased biomass production of shoots and roots. Plant survival decreased when cut frequently to 2 cm.

When managed appropriately, maintaining a minimum residual height and allowing adequate recovery time following grazing, native and naturalised pastures can produce high-quality forage and high herbage mass (Robinson and Archer 1988; Earl 1998; Nie and Zollinger 2012). In pastures dominated by warm season species, the addition of legumes will enhance forage quality through the winter and spring. Supplementation with non-protein nitrogen or bypass protein through the winter months will encourage intake and utilisation of warm season native species (Chapter 16). Where there is a base of

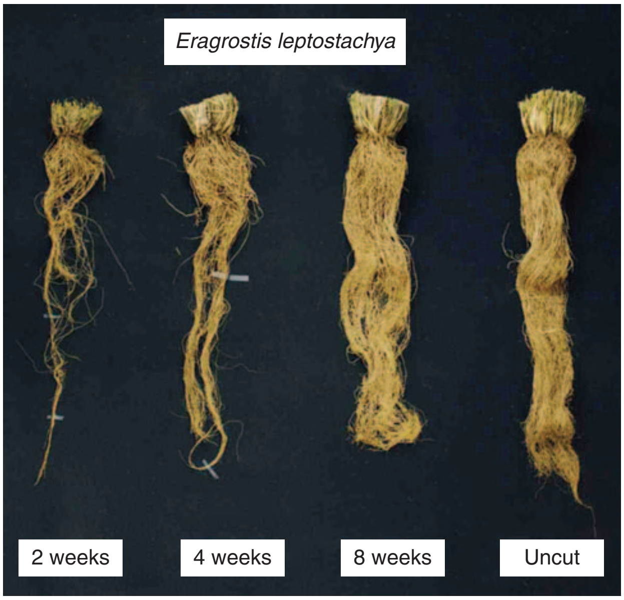


Figure 15.11: Effect of defoliation interval on the root system to 50 cm depth of paddock lovegrass (*Eragrostis leptostachya*), a desirable warm season native perennial grass of the northern slopes and tablelands of NSW. Plants were cut to 3 cm height every two, four and eight weeks. The treatment on the right was uncut for 12 months. Source: Earl (1998).

desirable native pasture species, the cheapest and safest option for improving those pastures is through appropriate grazing management.

Fire and grazing management

Fire has long been recognised as an important tool for managing pasture in northern Australia, but there is significant debate regarding its importance, frequency and purpose in the rangelands (McIvor *et al.* 2010). Table 15.4 lists the perceived advantages and disadvantages of fire as a management tool in northern Australia. Although there is considerable debate, burning is regarded as a critical tool in managing woody vegetation to maintain the tree–grass balance. The balance is primarily determined by average annual rainfall and available soil nutrients but can be altered through disturbance events such as fire and grazing (Scott *et al.* 2010). Excluding fire from savannas over a 20-year period may result in a succession from open woodland to closed forest, with a reduction in herbage mass production of the grasses (Burrows *et al.* 1990).

Burning of native pasture has the effect of reducing herbage mass and subsequently increasing the nutritional quality of the pasture regrowth (Orr *et al.* 2005). A study analysing the impact of fire on animal production in black speargrass pasture produced no conclusive results in terms of liveweight gain in beef cattle; the primary influence was the herbage mass production (yield) following the fire due to variation in seasonal rainfall following the burn. Low rainfall following burning had a significant adverse effect on animal production in the Wambiana trial, where cattle had to be removed from the site due to poor pasture recovery (O'Reagain *et al.* 2007)

Table 15.4: Perceived benefits and risks of fire as a management tool in northern Australia

Advantages	Disadvantages
Promotion of 'green pick' for stock	Adverse effect on air quality
Removal of dead grass to promote new growth	Creation of bare ground and potential erosion
Weed control	Depletion of soil nutrients, particularly N and S
Change pasture composition grass – legume	Adverse effect on water quality
Change pasture composition tree – grass	Risk to fire-sensitive species and habitat
Aid seedbed preparation	Risk to infrastructure
Muster livestock	Risk to humans
Control animal movement	Risk of forage shortage with poor season
Control burn to reduce wildfire risk	Undesirable species may be promoted
Control pests such as ticks	Forage burnt a 'waste' of grazable resource

Source: Adapted from McIvor *et al.* (2010).

The effect of fire will be influenced by the time of burn (season), the intensity of the burn and the frequency. The type of burn will be determined by the amount of fuel available, the primary fuel being perennial grasses (McIvor *et al.* 2010). The fuel load is critical: at least 800–1000 kg DM/ha is required for fire to carry (Burrows *et al.* 1990). This may be increased by resting pasture during the late wet season in advance of the burn.

In the absence of an effective fire regime, open grassland woody species such as prickly acacia, mimosa and gidgee may increase (DERM 2011). Increases in these species have been attributed to increased grazing pressure and a change in the fire regime (Burrows *et al.* 1990). Fire is regarded as the most economically viable option for the control of woody weeds in rangelands. A survey of 375 northern Australian beef producers (Bortolussi *et al.* 2005a) found the majority (67–100% between regions) routinely used fire to reduce woody weeds or dry herbage mass and wildfire risk, and in grazing management.

Fire has been used to improve the distribution of animals across the landscape (Ash *et al.* 1997). It has a role in the preparation of a seedbed for the establishment of introduced grasses such as buffel grass and has also been used in the introduction of stylos (*Stylosanthes* spp.) in native pastures (McIvor *et al.* 2010).

In the high-rainfall zone, fire is used frequently in native pastures for four main purposes (Lodge and Whalley 1989): to control woody species, to reduce hazard (usually during the cooler months to reduce a buildup of herbage mass), to remove the bulk of dry material to stimulate herbage growth and to prevent wildfires in sensitive plant communities.

IMPROVED PASTURES

Increasing the quality and production of any pasture including those dominated by native species is a form of pasture improvement (Ayres 2011). The more conventional definition of improved pastures is areas sown to introduced pasture species. The practice of sowing introduced pasture species is most commonly adopted in the high-rainfall southern areas where rainfall tends to be winter dominant and introduced cool season species are better adapted for survival and production. Areas in the high-rainfall zones of the northern and central slopes and tablelands are often sown to introduced species to achieve an increase in pasture production.

Historically, a replacement philosophy has been the basis of pasture improvement on the assumption that, once established, sown pastures are effectively permanent (Bolger and Garden 1998). The most commonly sown species of the temperate pasture zones of NSW and southern Australia are ryegrass (*Lolium perenne*), phalaris (*Phalaris aquatica*), cocksfoot (*Dactylis glomerata*) and tall fescue (*Festuca arundinaceae*), usually in combination with white clover (*Trifolium repens*) in high-rainfall areas or subclover (*Trifolium subterraneum*) (Wolfe 2010). The combination of drought, inadequate fertiliser and poor grazing management has resulted in a decline in productivity, reduced persistence and replacement by annual and native species in many sown temperate pastures (Bolger and Garden 1998).

The area of sown pasture in northern Australia is ~7 million ha (Quirk 2010). Buffel grass is the most widely sown species, constituting over 75% of plantings (Peck *et al.* 2011). It is estimated to be the dominant species over 5.8 million ha and described as common on an additional 25.9 million ha in Queensland. As for the native pastures described earlier, the decline in sown species is a major cause of concern. It is estimated that carrying capacity from established buffel grass pastures has declined by up to 50% across the state. The introduction of legumes, in particular *Stylosanthes* spp., into these pastures is seen as the major opportunity to address the decline in pasture production and quality (Orr 2005; Peck *et al.* 2011).

Other northern introductions include the subtropical species Rhodes grass (*Chloris gayana*), purple pigeon grass (*Setaria incrassata*) and bambatsi panic (*Panicum coloratum*), primarily in the subhumid/semi-arid zone. In the northern region of the humid coastal zone signal grass (*Brachiaria decumbens*) and guinea grass (*Panicum maximum*) are most common (Wolfe 2010). More recently there has been increasing interest in the introduction of subtropical pasture species as far south as the northern and central slopes regions of NSW. Subtropical species such as those listed in Table 15.2 are sown into paddocks with a long cultivation history to enhance pasture production when restoring cropped land.

Total replacement of degraded pastures with exotic species requires a significant capital investment, with costs of $350–480+/ha (Burge and Nie 2012; Evergraze 2012). In northern areas, the replacement of pastures is no longer considered economic because of fertiliser costs (Orr 2005). Another significant factor is the perception among producers that the biggest costs of sowing pasture are failure to establish and poor persistence (Quirk 2010; Burge and Nie 2012). In the high-rainfall zone, the majority of graziers expect that successfully established sown species will disappear within 10 years (Kemp *et al.* 1996).

In high-rainfall zones a minimum of 12 months planning is required to ensure that a paddock is adequately prepared for sowing (Ayres 2011). Another 'cost' often not considered is the period of time the area is out of production in the lead-up to sowing and during the post-planting establishment phase. The MLA pasture improvement calculator (MLA 2012b) is a valuable tool in the calculation of establishment costs, ongoing maintenance costs and time to break-even.

In addition to the capital cost, other factors to be considered in any decision to replace a pasture include the planned end use, livestock requirements, landscape factors, grazing management and likely return on investment (Ayres 2011). In tablelands regions, the average payback period for sown pastures is about nine years (Bolger and Garden 1998; EverGraze 2012) making grazing management of these pastures critical to ensure that, once established, pastures persist long enough for a positive financial return on the investment.

There are additional risks with pasture replacement: the exposed soil leaves the cultivated area vulnerable to erosion, the risk increasing with slope (Scott 1997). A common mistake is to increase stock numbers in anticipation of increased pasture production (Simpson *et al.* 1998). In situations where pasture does not successfully establish, the relatively greater grazing pressure associated with higher numbers of livestock will compromise the productive potential of those pastures in the short and long terms.

Oversowing or direct drilling of introduced species into existing native or natural pastures is an economic and more widely practised method of improving pasture quality with the introduction of species. This practice minimises soil disturbance and retains more of the desirable components of the existing pasture. Sowing cool season species into a native pasture dominated by warm season grasses takes advantage of the phenological differences between species. The increased pasture diversity increases the productive potential of the pasture.

Annual pastures

In much of the grazing land of southern Australia, deep-rooted native perennial grasses have been replaced by annual species (Heng *et al*. 2001). Generally inflexible stocking rates and long periods of continuous grazing have resulted in the transition from perennial to annual dominated pastures (Westoby *et al*. 1989). The most commonly occurring annual grass species are silver grass (*Vulpia* spp.), barley grass (*Hordeum* spp), wild oats (*Avena* spp.) and bromes (*Bromus* spp.) (Tozer *et al*. 2008; Kahn *et al*. 2010). The productivity of these pastures has increased significantly with the introduction of annual legumes.

Originating in the 1930s, winter-growing annual legumes sown in combination with Wimmera ryegrass (*Lolium rigidum*) were the basis of the ley pasture system used in the Australian wheat belt (Seligman 1996; Wolfe 2010). The most widely used species were subclover and medics (*Medicago* spp.). By 1970, over three-quarters of the wheat–sheep belt had incorporated pasture leys using self-seeding legumes and annual species, with productivity maintained through the use of superphosphate and persistence enhanced by the hard-seeded characteristics of the legumes (Seligman 1996). From the 1980s the productivity of these pastures declined due to several factors including reduced fertiliser inputs, poor grazing management, variable seasons and a rundown in seed reserves (Nichols *et al*. 2012).

An estimated 29.3 million ha of southern Australia has been sown to subclover, making it the most widely sown legume in Australia. Its capacity to withstand close grazing and persistence in the seedbank are the major characteristics contributing to its success (Nichols *et al*. 2012). Annual medics, primarily burr medic (*Medicago polymorpha*) and barrel medic (*Medicago truncatula*), collectively have been sown over an area of 24.6 million ha in southern regions and have become naturalised over an additional 20 million ha. Hot dry summers and cool wet winters characterise the Mediterranean environment where annual pastures predominate. The longer and hotter the summer period, the greater the prevalence of annual species (Seligman 1996).

In recent years there has been increasing interest and research effort into a wide range of annual and short-lived legume species more suited to diverse environments, with adaptations suited to new and existing farming systems (Nichols *et al*. 2007). In a comprehensive review, the authors listed the range of newly released cultivars designed to address the perceived lack of diversity and deficiencies of traditional annual legumes. Species include serradella (*Ornithopus sativus*), biserrela (*Biserrela pelecinus*), sulla (*Hedysarum coronarium)* and a range of new clover (*Trifolium* spp.) and medic (*Medicago* spp.) varieties.

FORAGE CROPS

In the high-rainfall zone, forage crops are most often sown as an initial phase in a pasture renovation program or for the specific purpose of providing high-quality forage to finish cattle.

One or two years of a forage crop, with the objective of reducing the weed burden before planting perennial pasture, is a common strategy. The same economic and environmental risks associated with establishment of introduced pastures will influence the decision to plant forage crops.

In most grazing enterprises, the seasonality of forage production creates challenges for management. Forage crops such as oats, rye and triticale, which show high winter growth rates, can complement pasture production in temperate and Mediterranean environments (Porqueddu *et al*. 2005). The range of *Brassica* spp. sown for forage may also be high-yielding and provide a high-quality palatable feed source. Depending on the environment and soil fertility, summer crops such as pearl millet or forage sorghum may be alternated with annual ryegrass.

In general there is a trade-off between high short-term total production of a forage crop and the more stable annual production cycle of a perennial pasture (Porqueddu *et al*. 2005), not withstanding environmental variability. Wylie (2007) suggested that pastures in south-east Queensland could produce as much feed as forage crops with lower costs. The same author noted the need to factor in other ‘costs’ associated with forage cropping, including soil structural decline and loss of organic matter.

Any area sown to a forage crop reduces the area of pasture available for animal production, and the opportunity cost of the forgone pasture production needs to be factored into the cost of the cropping program. The economics of grain compared to forage crops and pasture change regularly. When beef prices are high and grain prices low, pastures which are well managed are more profitable (Wylie 2007). Pratley and Virgona (2010) suggested there is little evidence of any economic advantage of a forage crop in comparison to well-managed pasture, although there have been few assessments of the practice within a whole farm system.

Figure 15.12: Pasture cropping – oats sown into an existing native pasture on the central west slopes of NSW.

A relatively new concept is that of pasture cropping (Seis 2004) and a variation on the same theme, referred to as No Kill Farming (Maynard 2013). Pasture cropping generally applies to the direct drilling of winter cereal crops into an existing stand of summer active perennial pasture (Fig. 15.12). It has been a common practice in the north coast region of NSW to direct drill annual rye grass and oats into existing summer active pastures to provide higher-quality forage for cattle during winter. Pasture cropping offers a multi-purpose option to graziers on the slopes and tablelands of NSW and more traditional cropping areas.

The proposed benefits of pasture cropping include maintenance of groundcover, increased herbage mass production, higher soil water utilisation, reduced nitrogen availability and the ability to graze pastures up to the date of sowing (Bruce and Seis 2005). Costs of sowing oats were calculated at $89.19/ha in 2003 and yields of 4.3 t/ha were comparable to conventionally sown crops (Seis 2004). Although Millar and Badgery (2009) found no yield advantage compared to conventionally sown crops, they acknowledged the value of pasture cropping as a low-risk low-input strategy to achieve multiple income options from grazing and grain.

WEEDS

Over 2500 plant species have been described as having an adverse impact on the environment and the cost of control is an estimated $400 million per year to Australian agriculture (Sinden *et al.* 2004). Despite such expenditure there is little evidence that conventional approaches to weed management have provided effective long-term control of any species. Applications of herbicide, cultivation, slashing, burning and some forms of grazing most often simply treat symptoms of a greater problem with ecosystem function and do little in terms of addressing why a weed might be present in sufficiently high numbers that action is required.

There are numerous definitions of a ‘weed’. A common description is that a weed is a plant growing out of place. Most often it depends on what species are growing in association within the community and the relative palatability of the range of species in a particular pasture. The description of a species as a desirable or undesirable component of the pasture is up to the land manager’s perception of its palatability, function and contribution to the total herbage mass.

Weeds often occur in a pasture when desirable species are lost or weakened gaps occur in the canopy, allowing species present in the seedbank to colonise those spaces (Bullock *et al.* 1995).

The germinable seedbank of most soils is vast. A study of two soils in the New England region of NSW identified 59 390 germinable seeds/m^2 on a granite soil and 45 430/m^2 on a basalt soil (Earl 1998). A high proportion of the seeds that germinated were generally considered undesirable for pasture production. The majority of species considered as weeds are annual species, the seeds of which may remain viable for many decades. The germination of many of these species is enhanced by exposure to light (Boyd and Van Acker 2004).

A healthy diverse perennial pasture should ideally have a broadleaf component of 10–15% of the total herbage mass (MLA 2004; Kahn and Earl 2005). Broadleaf plants are often identified as weeds but, in low numbers, these species can make a significant contribution and add to the diversity of the diet of beef cattle. Broadleaf plants concentrate minerals in their tissue to a greater degree than grasses and the tap roots enhance soil structure. Generally, the soil surface area that these plants occupy is small; only when populations of broadleaf plants become excessive will pasture production be adversely impacted.

In high-rainfall areas receiving an average 550 mm annual rainfall or more, managing the grazing of pastures to maintain maximum groundcover and at least 1500 kg DM/ha at all times is the most effective method to control the presence of annual species. Maintaining a dense canopy cover limits the potential for these plants to germinate. Of course groundcover will vary with soil and land type but in regions where average rainfall is below 550 mm a more realistic target level of cover may be 80%. Regardless of the environment, maximum groundcover should be the goal as it is the best way to reduce the impact of undesirable species (Chapter 19).

Methods of control

Various control measures available to graziers, some more applicable than others in different regions. Some of the more common approaches and their effects are listed.

Grazing

A common approach to minimising the presence of undesirable plants in pasture in high-rainfall zones is intense grazing, whereby animals remain on an area until those plants are grazed (Jones 2000). However, this approach reduces animal production and usually, by the time the target species is grazed or impacted, all other desirable pasture plants have been overgrazed and thus weakened. This reduces their competitive ability and inevitably gaps will be created in the pasture, allowing other species to emerge – usually more undesirable species (Bullock *et al.* 1995)

With the use of high stock density, target species may be physically impacted (trampled) by cattle, which has a similar effect to defoliation of the plants. This physical impact reduces the biomass of plants and an adequate period of rest following grazing allows the more desirable pasture components to more effectively compete for resources. The cheapest and most effective method to control undesirable species is to maintain a dense, vigorous perennial pasture base with maximum groundcover, using the principles of good grazing management (Jones 2006).

Species of grazer

The inclusion of sheep or goats into the grazing area may assist with the control of some species and complement the grazing pattern of beef cattle. The use of goats to control woody species is increasing (Hart 2001; Anon 2007) and producers have reported success using goats to reduce the impact of blackberries. Sheep and goats have different selection preferences and grazing patterns from those of cattle, generally preferring a higher proportion of herbs in their diet (Fraser *et al.* 2009).

Fire

Controlled burning is often used in natural pastures of northern NSW, Queensland and the rangelands to reduce large volumes of unpalatable, ungrazed plant material and woody weeds. The intensity and timing of a controlled burn will influence the amount of vegetation removed (Lodge and Whalley 1989). Most often it is the conditions and management which occur after the fire that determine its success. Fire has the effect of reducing biomass and 'opening up' an area but it can also create bare ground and destroy litter and organic matter on the soil surface. Frequent burning will reduce fire-sensitive species in the pasture. It is important to apply grazing management practices which will reduce the need for such action on a regular basis.

In northern Australia, fire is the most cost-effective approach to control woody plants (Burrows *et al.* 1990). Bortolussi *et al.* (2005b) reported that over 68% of landholders surveyed had woody weeds on their properties and the majority used fire as a control measure.

Mechanical

Mechanical methods of control include clearing, cultivation, slashing and mulching. In northern Australia, clearing of woody weeds in advance of sowing pastures is a common practice (Bortolussi *et al.* 2005c). Cultivation may destroy or damage existing plants and reduce seeding but the action of cultivating soil inevitably creates bare ground, which enhances the opportunity for countless seeds present in the seedbank to germinate. Successful use of cultivation to establish pasture in degraded areas usually requires repeated application of herbicides over time to reduce the germinable seedbank and limit competition with new pasture seedlings.

Slashing or mulching may be used to reduce a bulk of unpalatable herbage mass or reduce the opportunity of undesirable species to set seed. The cutting height is an important consideration in this process. Ideally, the cut should be of sufficient height to achieve the desired effect without damaging the desirable pasture species. An adverse effect of slashing large amounts of plant material is that the cut vegetation often forms a thatch that lies over the area, limiting light to the plants below and restricting growth. The breakdown of this material is by oxidation rather than biological decay, as the ability of soil biota to access the thatch laying above the soil surface is limited. Slashing in advance of grazing livestock, particularly at high density, means that the movement of cattle allows them to trample organic material and encourage contact with the soil surface. Mulching of plant material results in the creation of smaller particle sizes which are more likely to contact the soil surface and break down more rapidly.

Herbicides

There is a large range of products and application techniques manufactured for control of plant species (Ensbey 2009; Anon 2013a). The mode of action usually targets specific plant enzyme systems or hormones, block chemical reactions or kill plants by contact or translocation. Common approaches include:

- selective herbicides, which target species within a particular functional group such as broadleaf plants, annual or perennial grasses, sedges or woody weeds. It is important to note that these chemicals are not so specific – desirable species in the same group may be contacted and damaged;
- spray graze techniques, generally applied for the control of broadleaf species in combination with high grazing pressure soon after application;
- spray topping, designed to reduce the seed production of annual grasses at flowering;
- spot spraying, which enables specific plants to be targeted. It is generally limited to larger more obvious plants within a sward;
- wick wiping, which requires the target species to be taller than the surrounding herbage. It is usually applied after an area has been grazed, exposing the taller undesirable plants;
- basal barking, which is useful for multi-stemmed trees and shrubs, regrowth, thin-barked trees and saplings. It involves spraying the circumference of the stem of the target;
- stem injection, which involves drilling through the bark and into the sapwood of the tree. The herbicide needs to be applied within 15 seconds to be taken into the plant tissue;
- cut stump method, which involves cutting the tree or shrub off at the base and applying the herbicide solution to the stump immediately. A similar method, referred to as cut and swab, is useful for vines and multi-stemmed shrubs.

Target groups

Broadleaf species

The greatest representation of undesirable pasture plants comes from the Family Asteraceae (Fig. 15.13). These include all the thistles (*Carthamus lanatus*, *Cirsium vulgare*, *Silybum marianum*, *Onopordum* spp.) and species such as fire weed (*Senecio madagascariensis*), fleabane (*Conyza* spp.), cape weed (*Arctotheca calendula*) and Bathurst burr (*Xanthium spinosum*), just to name a few. Other key contributors are from the Families Chenopodiaece, Amaranthaceae and Polygonaceae. A feature of most members of these Families, which are generally classified as weeds, is the potential to produce large numbers of very small seeds which require light for germination (Young *et al*. 2011). Maintenance of maximum groundcover effectively limits the opportunity of these species to germinate and establish.

Annual grasses

The most common annual grasses in pasture environments are cool season species such as *Vulpia* spp., barley grass (*Hordeum vulgare*) and soft bromes (*Bromus* spp.). These species can provide valuable forage in late winter

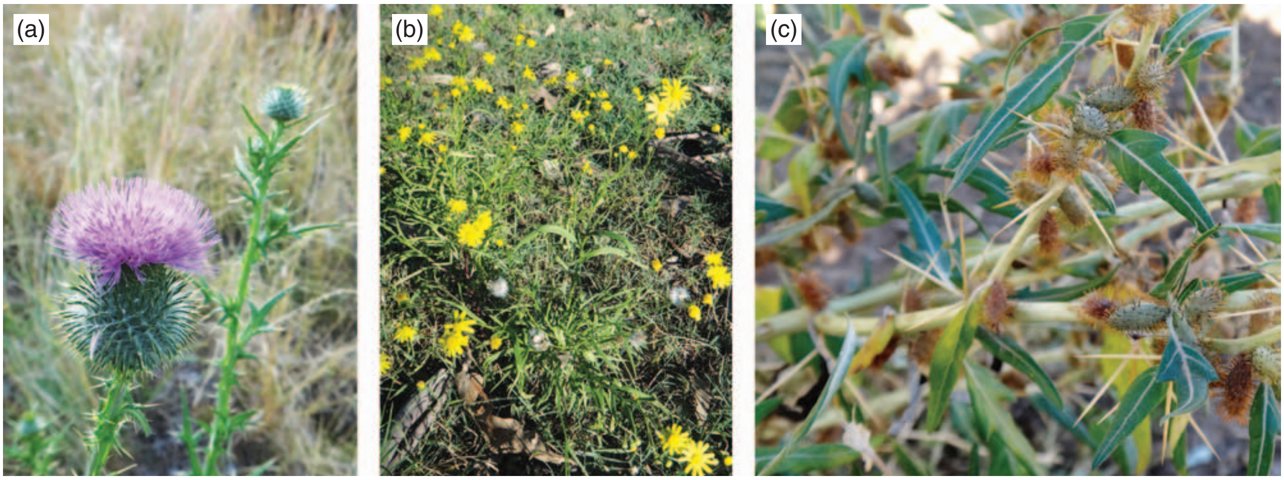


Figure 15.13: Common weeds of grazed pasture in the high-rainfall zone, Family Asteraceae. (a) Spear thistle (*Cirsium vulgare*). (b) Fire weed (*Senecio madagascariensis*). (c) Bathurst burr (*Xanthium spinosum*).

and spring but can also dominate herbage mass as the season progresses. They emerge from areas of low groundcover and their ability to dominate arises from their vast seed production potential and presence in the seedbank. A total of 2921/m^2 *Vulpia* spp. seedings germinated from topsoil collected from a pasture in the New England region of NSW (Earl 1998). These species may germinate at any time from autumn and have the capacity for rapid growth, effectively outcompeting perennial grasses for resources. Maintaining maximum perennial pasture cover is the most effective method to reduce the incidence and impact of these species.

Perennial grasses

Several less desirable perennial grass species are increasing in prevalence and usually categorised as weeds. Species such as serrated tussock (*Nassella trichotoma*), African lovegrass (*Eragrostis curvula*), Coolatai grass (*Hyparrhenia hirta*), giant Parramatta grass (*Sporobolus pyramidalis*), bent grass (*Agrostis capilaris*) and Chilean needle grass (*Nassella neesiana*) are generally considered of low forage value and often dominate large areas of grassland. With the exception of Chilean needle grass, this group of perennial grasses is particularly well adapted to areas of inherent low fertility (Harden 1993), low organic matter and low groundcover, generally areas that could be described as degraded pastures or grassland. The presence of these species adds to that status.

Most conventional methods of weed control (e.g. herbicide application, cultivation, burning) applied to undesirable perennial grass species generally create the conditions for them to extend their dominance. In contrast, Chilean needle grass is most prevalent in high-fertility basalt soils of the northern and central tablelands of NSW, although the methods outlined above generally have the same effect in contributing to the spread of the species. Where there are large populations of perennial grass weeds, it is often uneconomic to apply herbicides and there is an associated environmental risk to non-target species (McArdle *et al.* 2004). Where the terrain allows, the most effective chemical control of these species is achieved with wick wiping.

Woody weeds

There are two groups of particular concern in northern Australia: the introduced thorny tree *Acacia nilotica* is of greatest concern, having increased since the 1970s. The most important native species are gidgee (*Acacia cambagei*) and mimosa (*Acacia farnesiana*) (Burrows *et al.* 1990). Fire is usually the most economic approach to control these species. Although ringbarking and stem injection are other options, the majority of woody plants are too small for these measures to be effective.

Woody weeds are widespread in the north and central Australia. Across the northern regions, >68% of producers reported the presence of woody weeds on their properties. Eucalypt (*Eucalyptus* and *Corymbia* spp.) and wattle (*Acacia* spp.) regrowth were the most common problem species identified. Others of more regional significance include Parkinsonia (*Parkinsonia aculeata*), brigalow (*Acacia harpophylla*) and mesquite (*Prosopis* spp.) (Bortolussi *et al.* 2005b).

Integrated management

There are many options for and approaches to controlling undesirable plants in a pasture or rangeland. Effective control will rarely be achieved with the use of a single approach. Whatever control method is adopted, the management that follows the treatment will determine whether the problem persists or recurs. Continuing the same management practice which created the conditions for an undesirable species to thrive will inevitably result in its return.

Most weed infestations occur on what is usually referred to as degraded land. A point of contention may be whether land is classed as degraded due to the presence of the weedy species, or whether the weed is present as a result of degrading processes created by management. In either scenario, soil health is poor and pasture production and therefore animal production will be below potential. In grazed pastures and grasslands, the most effective method of control is prevention through the maintenance of a dense vigorous pasture base by application of sound grazing management strategies (Huwer *et al.* 2005).

For effective management of species composition, it is necessary to identify the strengths and weaknesses of particular species in the pasture and understand how they respond to different management approaches. Targeting an individual species requires an understanding of the basic biology of that species. A plant's site-specific response to applied management provides an opportunity to exploit differences between pasture species, ideally for the benefit of the desirable components. By focusing attention on the desired landscape and pasture composition, changes in soil and pasture conditions may be directed in favour of the desirable species.

DECISION SUPPORT TOOLS

There are support tools to assist producers and researchers with assessing herbage mass, predicting pasture growth, reviewing management options, water and soil fertility issues, weather and climate impacts and elements of business management. The following list of easily accessible tools provides examples of the available resources.

Meat and Livestock Australia (MLA) offers a range of material to beef producers (<http://www.mla.com.au/News-and-resources/Tools-and-calculators>). It includes:

- a stocking rate calculator to predict carrying capacity;
- a feed demand calculator, that demonstrates the feed supply and demand over the year;
- a feed budget and rotation planner, that incorporates stocking rate and pasture growth rates to predict requirements and plan the grazing regime;
- a rainfall to pasture growth outlook tool, that uses historical soil moisture indices and rainfall to predict a three-month outlook to aid planning;
- a phosphorus tool, that aids in using soil test information to plan a fertiliser program;
- a pasture improvement calculator, developed by Evergraze, that calculates the costs of resowing pasture;
- a pasture picker, that provides information on the specific characteristics of a large range of species;
- a health cost–benefit calculator;
- a calving histogram calculator;
- a BeefSpecs calculator;
- a Beef CoP, that allows annual financial evaluation of the enterprise.

FutureBeef (2013), in association with MLA, recently developed the Stocktake Plus app <www.stocktakeplus.com.au>). Specifically designed for producers in northern Australia and based on user input, it is an on-site decision support tool that allows the user to estimate pasture growth and calculate feed budgets. It stores stock and rainfall records, calculates tree density and provides land condition assessment.

FutureBeef offers a range of short videos covering topics such as feed budgeting, tactical grazing options, land condition score, grazing land management, elements of livestock nutrition and animal production. The presentations are available at <www.futurebeef.com.au/resources/multimedia>.

CSIRO GrazFeed™ calculates the effect of available herbage mass and quality on livestock production. It allows the operator to evaluate the consequences of varying quality and quantity of pasture and supplements for animal liveweight gain (<http://www.grazplan.csiro.au/?q=node/2>).

CSIRO GrassGro™ uses climate data and local soil moisture data to test management options by simulating daily pasture growth rate of introduced temperate pastures and animal production via interaction with GrazFeed to predict intake. Management rules in GrassGro allow for various joining dates, stocking rates and supplementation programs (<http://www.grazplan.csiro.au/?q=node/1>).

MetAccess, developed by CSIRO Plant Industry, allows analysis of historical weather data. Using long-term meteorological data, it helps the user to assess the likelihood of weather events and quantify variability in the weather (<http://www.grazplan.csiro.au/?q=node/4>).

EcoMod is a tool for managing climate, designed for grazing system researchers in temperate, Mediterranean and subtropical Australia (Johnson *et al.* 2008). EcoMod is a simulation model to predict consequences of weather and management for pasture growth and utilisation, water and nutrient dynamics, animal production, irrigation and fertiliser application. (<http://www.climatekelpie.com.au/manage-climate/decision-support-tools-for-managing-climate/ecomod>).

Material designed specifically for graziers is available in the form of a glovebox guide (Kahn and Earl 2005). Based on measurement of herbage mass using a height:weight relationship, it includes a methodology to assess strengths and weaknesses of pastures and a simple approach to calculating pasture growth rates and feed budgets. These measures are the basis of the development and implementation of a whole farm grazing plan.

A wealth of additional MLA literature to support beef cattle graziers is available online at <http://www.mla.com.au/News-and-resources>. The state Departments of Primary Industries and Grassland Societies also offer material. These agencies, as well as many private organisations, offer a wide range of industry-based training courses covering all elements of grazing and pasture management.

MANAGING DROUGHT

One of the most certain features of grazing in all grasslands and rangelands of Australia is the uncertainty of the climate. Periods of low and variable rainfall are a feature of the Australian environment (Fitzhardinge 2012; BOM 2013). Drought may be defined as a deficiency of rainfall or a deficiency of herbage mass, as the two issues are closely related. Through the effect on pasture growth, rainfall and temperature have a major impact on livestock enterprises (Howden *et al.* 2008). While there is no doubt about the influence of rainfall on plant growth, the effective use of that rainfall will determine the efficiency of conversion into plant material and the susceptibility of a property to be drought-affected.

Any plan to deal with a deficiency of rainfall will depend on the relative reliability of rainfall in a particular region as well as the manager's attitude to risk. To ensure the persistence of the pasture base and sustainable production post-drought, it is critical that the stocking rate not exceed the carrying capacity of the property and that the appropriate level of utilisation is maintained. 'Getting the stocking rate right' has been identified as a major challenge for the grazing industry (Stafford Smith *et al.* 2007). Failing to do so will compromise potential pasture productivity when favourable growth conditions return. Regular monitoring of the available herbage mass is an essential part of the process.

Drought, in combination with the failure of management to adapt to conditions of low rainfall and lower than average pasture production in a timely manner, is considered a primary cause of declining land condition (Bolger and Garden 1998; Wolfe and Dear 2001). Overutilisation of pastures accelerates land degradation processes. The progression consists of a general increase in stock numbers during above-average rainfall years, with sporadic periods of drought causing some decline in resource condition. With extended dry conditions stock prices fall, making it difficult, or considered uneconomic, to destock. As drought increases in severity, utilisation increases and the land degrades further (McKeon *et al.* 2009). With the decline in the productive potential of the land, reverting to the previous levels of stocking will inevitably continue the trend to overutilise, and the degradation process will continue.

Symptoms of pasture decline often occurring as a consequence of drought in combination with excessive grazing pressure include:

- loss of desirable pasture species, native and introduced (Tothill and Gillies 1992; Ash *et al.* 1997; Kemp and Dowling 2000; Stafford Smith *et al.* 2007; Cullen *et al.* 2009);
- increase in undesirable components including annual grasses (Kemp *et al.* 1996; Heng *et al.* 2001; Sanford *et al.* 2005);
- decline in soil fertility and soil structure (Donaldson 1998; Donnelly 1998);
- decrease in basal area of desirable species (McKeon *et al.* 2009);
- increase in bare ground (Donaldson 1998) and soil loss (Stafford Smith *et al.* 2007);
- decrease in soil carbon and organic matter (Young *et al.* 2005);
- increase in weeds, herbaceous and woody (Tothill and Gillies 1992; Ash *et al.* 1997; Stafford Smith *et al.* 2007);
- increase in soil surface runoff and erosion (Ash *et al.* 1997);
- increases in acidity and salinity (Donnelly 1998);
- decrease in herbage mass production (McKeon *et al.* 2009);
- decrease in carrying capacity.

It is generally accepted that widespread pasture and range condition decline is a consequence of inappropriate grazing management (Ash *et al.* 1997; Mason and Kay 2000) and some have concluded that the increased incidence of drought in many circumstances is management-induced (Donaldson 1998). It can hardly be coincidental that productivity improvement in the beef industry has slowed (Hunt *et al.* 2012). Improved approaches to grazing management can have an important role in restoring land condition, soil health and productivity (Kemp *et al.* 1996; Sanford *et al.* 2005; Cobon *et al.* 2009), and may be most critical during periods of drought.

With specified minimum residual herbage mass targets and an effective pasture monitoring program, graziers will be well placed to make informed decisions based on available herbage mass, livestock requirements and the probability of rainfall at any stage of the year. In the high-rainfall zone, planning to maintain a minimum residual herbage mass of 1500 kg DM/ha allows a degree of flexibility and the capacity to 'buy time' in a drought situation. Although the optimal residual will vary between regions, maintaining maximum groundcover will enhance pasture growth and provide some latitude in preserving the resource base in the long term.

Summer-dominant rainfall regions of northern Australia frequently experience a protein drought through the winter months when pasture quality declines as the winter progresses (Wilson and Simpson 1994). By managing grazing and pasture through the growing period to ensure there is adequate residual herbage mass to maintain livestock through the period of no growth, supplementation of cattle with a bypass protein product or urea may enhance the utilisation of low-quality pasture (Chapter 16).

An additional consideration in high-rainfall areas is that below 2000 kg DM/ha the feed intake of cattle becomes limited (MLA 2004). Any time the energy normally provided by pasture is substituted with an imported energy source (e.g. in the form of hay or grain), there is a high probability that the desirable components of the pasture will be overgrazed and by definition it will degrade. Management strategies adopted during periods of drought with the goal of maintaining the pasture resource will have a positive influence in enhancing the productive potential of pastures post-drought and in subsequent years.

In northern Australia, stock numbers are often based on a nucleus of self-replacing herds (McKeon *et al.* 2009). Breeding enterprises have less flexibility in their capacity to change stock numbers in response to lower than anticipated pasture growth. Conservative stocking and utilisation rates may counter this lack of flexibility but also result in lower than optimal levels of animal production. In severe drought, maintenance of constant stock numbers will likely result in excessive utilisation (McKeon *et al.* 2009). One strategy may be to identify, well in advance, stock that will be culled when stocking rate exceeds carrying capacity. Where monitoring has identified critical dates in the absence of pasture growth or rainfall, stock numbers may be quickly reduced. Another alternative may be to trade stock opportunistically, based on predicted pasture growth, or to utilise pasture growth in excess of that required by the breeding herd. The strategy must take into account a range of factors including the type of enterprise, the stage of the season and probability of rainfall, available resources and manager's attitude to risk.

Since 1961, in northern Australia the reduction in pasture cover and forage production have been relatively greater than the decline in rainfall and the periods of drought recovery have been longer than the drought periods (McKeon *et al.* 2009). The appearance of any or all of the symptoms of pasture and range decline at any time will increase the landscape's susceptibility to further degradation during periods of low rainfall. In the high-rainfall zone, it is rare to record zero precipitation during any month. In regions other than the monsoonal north, the majority of rainfall events recorded in a 12-month period are <5 mm (BOM 2013a). Maximising the value of these small rainfall events may well influence the survival of desirable perennial plants.

Managing cattle grazing to increase the perennial component of pastures, groundcover, soil organic matter, root depth and soil water infiltration rate enables pastures to take advantage of small rainfall events and survive until the next significant rainfall (Heng *et al.* 2001). Perennial grasses are tolerant of grazing, they have evolved to withstand frequent defoliation and to regenerate leaf area following defoliation. Native perennial grasses are well adapted to tolerate periodic drought (Whalley and Belloti 1997). The capacity for producing fine roots with the ability to access vast areas deep into the soil profile equips them well for surviving periods of moisture stress. Perennial grasses cannot tolerate constant depletion of energy stores through frequent severe defoliation, which limits their capacity to access water and nutrients (Donnelly 1998). Their survival and persistence is essential to protect the pasture base, in improving the rate of pasture recovery following drought and the productive potential in subsequent seasons.

Grazing and pasture management to maximise pasture growth rate, promote root growth, optimise water infiltration rate and encourage perennial species diversity during average and more favourable seasonal conditions is an effective drought mitigation strategy. With general predictions of climate change suggesting a decrease or no change in rainfall and an increase in temperature, it is highly likely that the incidence of drought conditions will increase (McKeon *et al.* 2009). Frequent measurement of available herbage mass and predicted animal requirements will be essential to ensure livestock carrying capacity is maintained at levels that will achieve appropriate utilisation of pasture or rangeland and ensure the ongoing productive potential of the resource base (Henry *et al.* 2002). A grazing plan can assist in the allocation of livestock to paddocks based on available herbage mass and the desired residual in each area.

CHALLENGE OF CLIMATE CHANGE

Increasing climate variability and the loss of desirable perennial grass species, resulting in the degradation of grasslands and loss of ecosystem function, are significant problems in Australian rangelands and temperate grasslands (Kemp and Dowling 2000; Stafford Smith *et al.* 2007; Millar and Badgery 2009). The primary impact of climate change on beef enterprises is expected to be changes in carrying capacity associated with pasture decline, and subsequently animal production (Stokes *et al.* 2012).

Graziers and pastoralists need to take a more proactive approach towards management of stock numbers and utilisation with a view to enhancing the resource base and improving the productive potential of the landscape if they and the beef industry are to remain viable. McCosker *et al*. (2010) reported that 50% of northern beef producers failed to cover expenses in five of the seven years to 2009 and Fitzhardinge (2012) found that profitability has been declining over the past 30 years. McEachern *et al*. (2012) noted a poor relationship between price received per kg and profit per DSE, highlighting the need to focus on reducing costs but noting that a high stocking rate was a prerequisite for high profit per DSE. With market pressures pushing towards increased stocking rates, coupled with climate uncertainty, in the absence of a proactive approach to grazing management the landscape will continue to deteriorate.

Declining terms of trade, falling markets and a focus on maximum production and productivity mean that destocking has not been an attractive option; cattle numbers have increased and contributed to the decline in land condition (Stafford Smith *et al*. 2007; Hunt *et al*. 2012). Most producers historically did not make stocking decisions until extreme events were affecting the enterprise (Ash *et al*. 2000). Healthy rangelands and pastures are essential for healthy social systems and for long-term productive and profitable agricultural industry (Fitzhardinge 2012; Ferguson 2012). With sympathetic resource management, future degradation may be avoided (Stafford Smith *et al*. 2007) and with appropriate grazing management the health and productive potential of grasslands and pastures may ultimately be restored to sustainably support higher stocking rates.

In high-rainfall zones of southern Australia, pastures are dominated by annual grasses and broadleaf species. Perennial grasses and clover are minor pasture components (Wilson and Simpson 1994). Regardless of a changing climate, any livestock production system based on annual species is vulnerable to seasonal variation in feed supply. Climatic variability increases the susceptibility of the landscape to further degradation. The variability and complexity in the rangelands of northern Australia make generalisations about the risks associated with climate change difficult (Cobon *et al*. 2009). However, it is clear that there is increasing agreement among the scientific community that the rate of climate change is accelerating and that it is a key issue for the rangelands and the beef industry (Howden *et al*. 2008; Cullen *et al*. 2009; McKeon *et al*. 2009).

Overstocking and inappropriate grazing management have often been blamed as primary causes of land degradation (Donaldson 1998). Degradation occurs as a result of the change in natural processes by the action of grazing animals remaining on an area for an excessive period. The primary effect of climate change on grazing lands is in modifying species composition (Cullen *et al*. 2009). The transition from perennial plant base to annual, reduction in plant cover, rooting depth and soil surface condition are all symptoms of excessive grazing (Williams and Hook 1998). The capacity for management of the grazing process to change landscapes in a positive way is vastly underestimated. Grazing livestock in a manner sympathetic to the natural cycles, and understanding how perennial grasses respond to their environment and imposed management are the basis for building resilience in grasslands and pastures and ameliorating the effects of climate change.

The capacity of grazing lands to sequester carbon in soil and increase carbon in vegetative biomass has long been identified as a major national sink (McKeon *et al*. 1998). Rather than being a source of anthropogenic emissions, as is so often quoted, when managed appropriately grazing livestock have the capacity to contribute significantly to reducing the impacts of rising levels of CO_2. More than 1 million km^2 has been identified as having the greatest opportunity to increase soil carbon (Anon 2013b), however, any activity which increases plant growth will effectively increase the potential carbon stored in the landscape. Australia has a great potential to harness sunlight energy, as it receives more than any other region (Ferguson 2012).

It has been suggested that annual average rainfall in the south-east of Australia is projected to decline by 10% and temperatures will increase by 1–2°C by 2030 (Cobon *et al*. 2009; Pratley and Virgona 2010). Under current land management and environmental conditions these changes will inevitably result in increased evaporation and less available rainfall. Across 30 paddock sites on the northern tablelands of NSW, Kahn and Earl (2005) recorded an average WUE of 6.3 kg DM/ha/mm over a 300-day period. This level of WUE was a function of 11.9 kg DM/ha average pasture growth recorded.

If, as implied by Kahn and Earl (2005), it is possible to increase WUE to 10 kg DM/ha/mm of rainfall with enhanced grazing management, improving the quality and production of perennial grasses with all the associated environmental benefits, such as increased water infiltration rate and soil organic matter content, would equate to an average pasture growth rate of 18.9 kg DM/ha.

Aiming to utilise 50% of this pasture growth would equate to a stocking rate of 9.5 DSE/ha. This stocking rate is higher than the average recorded across all sites in 2004 (7.5 DSE/ha) utilising more of the pasture grown (66%).

Managing livestock to build capacity in the landscape can more than offset the adverse effects of any reduction in rainfall and increase in evaporation resulting from climate change. Assuming a 10% reduction in rainfall over that recorded during the trial period, increasing WUE by a modest 10% to 7 kg DM/ha/mm would totally counter the effects of reduced rainfall. A key factor in increasing WUE and adaptation to mitigate the effect of lower rainfall is increasing the population of deep-rooted perennial plants (Cullen *et al.* 2009). Cobon *et al.* (2009) provided a range of adaptation responses to mitigate the impact of climate change, including managing pasture utilisation to maintain maximum groundcover.

CONCLUSION

It is a misnomer to refer to grazing as simply the exposure of plants to animals. The grazing process is a highly complex interaction between the animal, plant and soil and, depending on the management of that process, it can be restorative or degrading. Applied sympathetically, with a basic understanding of the interactions between the components and in tune with natural cycles, grazing livestock are critical to regenerating land, resulting in increased pasture production, soil health and ecosystem function. Soil and pasture health are the foundation of a healthy landscape and a productive, profitable beef enterprise.

The interaction of grazing animals, plants and soil is a dynamic process through which change in pasture is manifest in the relative vigour and abundance of plants, soil characteristics and land condition. The application of management to this process impacts on the potential productivity of pastures and rangeland. Management of the grazing process affects plant production and therefore animal production primarily through control of the defoliation of plants.

Control is applied through management of the frequency and intensity of grazing. The time that plants are exposed to grazing livestock and, more importantly, the time allowed for plants to recover from grazing have a significant influence on the productive potential of a pasture in terms of growth rate and species composition. The intensity of defoliation of individual plants will influence their individual contribution to this outcome and, through the influence on soil processes, the health of the pasture resource. By maintaining a minimum residual herbage mass, management has the capacity to direct changes and influence plant and animal production.

The concept that a ‘grazing system’ either works or does not is curious. With consideration of available resources, whatever grazing regime is implemented, the critical elements are the ability to measure herbage mass and to use that information to make informed decisions. The decisions must also account for livestock type, number and nutritional requirements, climate forecasts, environmental variability and how the grazing management is incorporated into the whole farm plan. A time-based or systematic approach to grazing management cannot possibly address the complexities of the grazing process – the soil/plant/animal interaction – and the constant variation in pasture growth response due to climatic and biotic factors. The effective management of any approach to grazing and pastures comes down to the skill of the manager and the level of commitment to their desired goals. The manager and the decisions made, ideally towards achieving a clearly defined set of goals, are the greatest influence on the sustainability and profitability of a beef enterprise.

Appropriate management of the grazing process is the most effective method available to graziers to enhance the productive potential of pastures, build resilience in the landscape (Chapter 19) and increase the carrying capacity and profitability of beef cattle enterprises. With a fundamental understanding of the ecological processes in grasslands, managers are better equipped to use their grazing livestock in combination with those basic, essential and free resources of rainfall, sunlight and CO_2 to maximum effect to enhance pasture and livestock growth.

REFERENCES

Allan CA (1994) *NSW Prograze Manual*. NSW Department of Primary Industries.

Alsemgeest V, Alchin B (2003) Comparison of continuous and cell grazing on woodlands in Central Queensland, Australia. *Proceedings of the 7th International Rangelands Congress,* 26 July–1 August, Durban, South Africa. (Eds N Allsopp, AR Palmer, SJ Milton, KP Kirkman, GIH Kerley, CR Hunt and CJ Brown).

Anonymous (1993) *Pastures*. www.ga.gov.au/image_cache/GA10693.pdf.

Anonymous2007) Goats beat sprays. *Ecologist* **37**, 11.

Anonymous (2013a) *Weed Application Methods for Herbicides*. <www.business.qld.gov.au/industry/agriculture/land-man-

agement/health-pests-weeds-diseases/weeds-and-diseases/controlling-weeds-property/physical-weed-control-methods>.

Anonymous (2013b) *Land Management Affects Soil Condition*. <www.daff.gov.au/natural-resources/soils/improving-improving-land-management-practices>.

Ash AJ, McIvor JG, Mott JJ, Andrew MH (1997) Building grass castles: integrating ecology and management of Australia's tropical tallgrass rangelands. *Rangeland Journal* **19**, 123–144. doi:10.1071/RJ9970123.

Ash A, O'Reagain P, McKeon G, Stafford Smith M (2000) Managing climate variability in grazing enterprises: a case study of Dalrymple Shire, north-eastern Australia. In *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems: The Australian Experience*. (Eds GL Hammer, N Nicholls and C Mitchell) pp. 253–270. Kluwer Academic, The Netherlands.

Ash A, Corfield J, Ksiksi T (2001) *The Ecograze Project: Developing Guidelines to Better Manage Grazing Country*. CSIRO, Townsville.

Ayres (2011) *Agriculture Today*. NSW Department of Primary Industries.

Badgery WB, Cranney P, Millar GD, Mitchell D, Behrendt K (2012) Intensive rotational grazing can improve profitability and environmental outcomes. In *Proceedings of the 27th Annual Conference of the Grassland Society of NSW*, 24–26 July, Wagga Wagga, pp. 85–91. Grassland Society of NSW, Wagga Wagga.

Baker G (2003) Cited in Gupta VVSR and Ryder MH (2003) Soil biology in pasture systems: knowledge and opportunity audit. Final Report BSC.007. Meat and Livestock Australia, Sydney.

Baldock JA (2008) *Factors which Influence Soil Carbon Levels*. <http://www.csiro.au/en/Outcomes/Climate/Adapting/Soil-Carbon-Levels.aspx>.

Baldock JA (2011) *Soil Carbon: The Basics*. <http://www.csiro.au/Outcomes/Environment/Australian-Landscapes/soil-carbon.aspx#a1>.

Baldock JA, Skjemstad JO (1999) Soil organic carbon/soil organic matter. In *Soil Analysis: An Interpretation Manual*. pp.159–170. CSIRO Publishing, Melbourne.

Bolan N (1991) A critical review on the role of mycorrhizal fungi in the uptake of phosphorus by plants. *Plant and Soil* **134**, 189–207. doi:10.1007/BF00012037.

Bolger TP, Garden DL (1998) Ecological sustainability: species persistence in grazing systems. In *Animal Production in Australia: Proceedings of the 22nd Biennial Conference of the Australian Society of Animal Production*, pp. 65–66. Australian Society of Animal Production, Armidale, NSW.

BOM (2013) *Living with Drought*. <http://www.bom.gov.au/climate/drought/livedrought.shtml>.

BOM (2013a) *Climate Data Online*. <http://www.bom.gov.au/climate/data/>.

Bortolussi BG, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005a) The northern Australian beef industry, a snapshot. 1. Regional enterprise activity and structure. *Australian Journal of Experimental Agriculture* **45**, 1057–1073. doi:10.1071/EA03096.

Bortolussi BG, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005b) The northern Australian beef industry, a snapshot. 4. Condition and management of natural resources. *Australian Journal of Experimental Agriculture* **45**, 1109–1120. doi:10.1071/EA03262.

Bortolussi BG, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005c) The northern Australian beef industry, a snapshot. 5. Land and pasture development pracices. *Australian Journal of Experimental Agriculture* **45**, 1121–1129. doi:10.1071/EA04013.

Boyd N, Van Acker R (2004) Seed germination of common weed species as affected by oxygen concentration, light, and osmotic potential. *Weed Science* **52**, 589–596. doi:10.1614/WS-03-15R2.

Briske DD (1986) Plant response to defoliation: morphological considerations and allocation priorities. In *Rangelands: A Resource Under Siege*. (Eds PJ Joss, PW Lynch and OB Williams) pp. 425–427. Australian Academy of Science, Canberra.

Briske DD, Richards JH (1994) Physiological responses of individual plants to grazing: current status and ecological significance. In *Ecological Implications of Livestock Herbivory in the West*. (Eds M Vavra, WA Laycock and RD Peiper) pp.147–176. Society for Range Management, Denver.

Brown JR, Stuth JW (1993) How herbivory affects grazing tolerant and sensitive grasses in a central Texas grassland: integrating plant response across hierarchical levels. *Oikos* **67**, 291–298. doi:10.2307/3545474.

Bruce S, Seis C (2005) Lift cover and reduce drainage with pasture cropping. *Farming Ahead* **162**, 1–2.

Bullock JM, Marriott CA (2000) Plant responses to grazing, and opportunities for manipulation. In *Grazing Management: The Principles and Practice of Grazing, for Profit and Environmental Gain, within Temperate Grassland Systems*. (Eds AJ Rook and PD Penning) pp. 27–32. British Grassland Society, Reading.

Bullock JM, Clear Hill B, Silvertown J, Sutton M (1995) Gap colonization as a source of grassland community change: effects of gap size and grazing on the rate and mode of colonization by different species. *Oikos* **72**, 273–282. doi:10.2307/3546229.

Burge S, Nie Z (2012) Reducing the cost of pasture establishment. Final Report B.PSP.0006. Meat and Livestock Australia, Sydney.

Burrows WH, Carter JO, Scanlan JC, Anderson ER (1990) Management of savannas for livestock production in north-east Australia: contrasts across the tree-grass continuum. *Journal of Biogeography* **17**, 503–512. doi:10.2307/2845383.

Butler JL, Briske DD (1988) Population structure and tiller demography of the bunchgrass *Schizachyrium scoparium* in response to herbivory. *Oikos* **51**, 306–312. doi:10.2307/3565311.

Butterfield J, Bingham S, Savory A (2006) *Holistic Management Handbook*. Island Press, Washington.

Charlton JFL, Wier JH (2001) TechnoGrazing™: a new grazing concept. *Proceedings of the New Zealand Grassland Association* **63**, 33–36.

Child MF, Milton SJ, Dean RWJ, Lipsey MK, Puttick J, Hempson TN, Mann GK, Babiker H, Chaudrey J, Humphrey G, Joseph

G, Okes NC, Potts R, Wistebaar T (2010) Tree-grass coexistence in a flood-disturbed, semi-arid savanna system. *Landscape Ecology* **25**, 315–326. doi:10.1007/s10980-009-9409-x.

Cobon DH, Stone GS, Carter JO, Scanlan JC, Toombs NR, Zhang X, Willcocks J, McKeon GM (2009) The climate change risk management matrix for the grazing industry of northern Australia. *Rangeland Journal* **31**, 31–49. doi:10.1071/RJ08069.

Cook G (1994) A simple explanation of time control grazing. In *Proceedings of the 9th Annual Conference of the Grassland Society of NSW.* <http://grasslandnsw.com.au/news/wp-content/uploads/2011/09/Cook-1994.pdf>.

Crawford MC, Grace PR, Belloti WD, Oades JM (1996) Below ground inputs of carbon by crops and pastures. In *Proceedings of the 8th Australian Agronomy Conference,* 30 January–2 February, Toowoomba. (Eds DL Michalk and JE Pratley). Australian Society of Agronomy, Toowoomba, Qld.

Cullen BR, Johnson IR, Eckard RJ, Lodge GM, Rawnsley RP, Walker RG, McCaskill MR (2009) Climate change effects on pasture systems in south-eastern Australia. *Crop and Pasture Science* **60**, 933–942. doi:10.1071/CP09019.

Dalal RC, Wang W, Mann S, Henry B (2004) Soil organic matter decline and restoration: principles and practices. *Natural Resource Management* **7**, 2–15.

DERM (2011) Managing grazing lands in Queensland. Queensland Department of Environment and Resource Management.

Donaldson S (1998) The role of animals in catchment management: how communities make change. a case study in the Namoi Valley. In *Animal Production in Australia: Proceedings of the 22nd Biennial Conference of the Australian Society of Animal Production,* pp. 39–46. Australian Society of Animal Production, Armidale, NSW.

Donnelly JR (1998) Sustainable grazing systems for farms in temperate Australia. *Animal Production in Australia. Proceedings of the 22nd Biennial Conference of the Australian Society of Animal Production* pp. 61–62. Australian Society of Animal Production, Armidale, NSW.

Doube B (2003) Cited in Gupta VVSR and Ryder MH (2003) Soil biology in pasture systems: knowledge and opportunity audit. Final Report BSC.007. Meat and Livestock Australia, Sydney.

Dowling PM, Kemp DR, Michalk DL, Klein TA, Millar GD (1996) Perennial grass response to seasonal rests in naturalised pastures of central New South Wales. *Rangeland Journal* **18**, 309–326. doi:10.1071/RJ9960309.

Earl JM (1998) The role of grazing management in the functioning of pasture ecosystems. PhD thesis. University of New England, Armidale, NSW.

Earl JM, Jones CE (1996) The need for a new approach to grazing management: is cell grazing the answer? *Rangeland Journal* **18**, 327–350. doi:10.1071/RJ9960327.

Edwards JH, Wood CW, Thurlow DL, Ruf ME (1999) Tillage and crop rotation effects on fertility status of a Hapludalf soil. *Soil Science Society of America Journal* **56**, 1577–1582. doi:10.2136/sssaj1992.03615995005600050040x.

Edwards GR, Parsons AJ, Bryant RH (2008) Manipulating dietary preference to improve animal performance. *Australian Journal of Experimental Agriculture* **48**, 773–779. doi:10.1071/EA08006.

Ensbey R (2009) *Noxious and Environmental Weed Control Handbook*. 5th edn. (Ed E van Oosterhout). Department of Primary Industries, Orange, NSW.

Evergraze (2012) *Pasture Improvement Calculator*. <www.evergraze.com.au>.

Ferguson J (2012) A sustainable future for the Australian rangelands. *Rangeland Journal* **34**, 27–32. doi:10.1071/RJ11056.

Fitzhardinge G (2012) Australia's rangelands: a future vision. *Rangeland Journal* **34**, 33–45. doi:10.1071/RJ11059.

Foran BD (1980) Change in range condition with distance from watering point and its implications for field survey. *Australian Rangeland Journal* **2**, 59–66. doi:10.1071/RJ9800059.

Fraser MD, Theobald VJ, Griffiths JB, Morris SM, Moorby JM (2009) Comparative diet selection by cattle and sheep grazing two contrasting heathland communities. *Agriculture, Ecosystems and Environment* **129**, 182–192. doi:10.1016/j.agee.2008.08.013.

Future Beef (2013) Future Beef Stocktake Plus app. <http://www.stocktakeplus.com.au/>.

Grace PR, Ladd JN, Robertson GP, Gage SH (2006) SOCRATES: a simple model for predicting long-term changes in soil organic carbon in terestrial ecosystems. *Soil Biology and Biochemistry* **38**, 1172–1176. doi:10.1016/j.soilbio.2005.09.013.

Greenwood KL, McKenzie BM (2001) Grazing effects on soil physical properties and the consequences for pastures: a review. *Animal Production Science* **41**, 1231–1250. doi:10.1071/EA00102.

Guitian R, Bardgett RD (2000) Plant and soil microbial responses to defoliation in temperate semi-natural grassland. *Plant and Soil* **220**, 271–277. doi:10.1023/A:1004787710886.

Gupta VVSR, Ryder MH (2003) Soil biology in pasture systems: knowledge and opportunity audit. Final Report BSC.007. Meat and Livestock Australia, Sydney.

Hall TJ (2011) Volume I: Investigating intensive grazing systems in northern Australia. Final Report B.NBP.0353. Meat and Livestock Australia, Sydney.

Hall WB, McKeon GM, Carter JO, Day KA, Howden SM, Scanlan JC, Johnston PW, Burrows WH (1998) Climate change in Queensland's grazing lands: II. An assessment of the impact on animal production from native pastures. *Rangeland Journal* **20**, 177–205. doi:10.1071/RJ9980177.

Hamilton EW, Frank DA (2001) Can plants stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. *Ecology* **82**, 2397–2402. doi:10.1890/0012-9658(2001)082[2397:CPSSMA]2.0.CO;2.

Harden G (1993) *Flora of New South Wales.* Vol. 4. University of New South Wales Press, Sydney.

Hart SP (2001) Recent perspectives in using goats for vegetation management in the USA. *Journal of Dairy Science* **84**, 170–176. doi:10.3168/jds.S0022-0302(01)70212-3.

Hattersley PW (1983) The distribution of C_3 and C_4 grasses in Australia in relation to climate. *Oecologia* **57**, 113–128. doi:10.1007/BF00379569.

Heng LK, White RE, Helyar KR, Fisher R, Chen D (2001) Seasonal differences in the soil water balance under perennial and annual pastures on an acid Sodosol in south-eastern Australia. *European Journal of Soil Science* **52**, 227–236. doi:10.1046/j.1365-2389.2001.00386.x.

Henry DA, Edirishghe A, Donald G, Hill M (2002) Monitoring pastures using satellite remote sensing. In *Animal Production in Australia: Proceedings of the 24th Biennial Conference of the Australian Society of Animal Production,* pp. 81–84. Australian Society of Animal Production, Adelaide.

Howden SM, Crimp SJ, Stokes CJ (2008) Climate change and Australian livestock systems: impacts, research and policy issues. *Australian Journal of Experimental Agriculture* **48**, 780–788. doi:10.1071/EA08033.

Hunt L, Ash A, McDonald C, Scanlan J, Bell L, Cowley R, Watson I, McIvor J, MacLeod N (2012) Seeking sustainable productivity improvements in the northern beef industry. In *Proceedings of the 17th Australian Rangeland Society Biennial Conference*, 23–27 September, Kununnurra. Australian Rangeland Society.

Huntly N (1995) How important are consumer species to ecosystem functioning? In *Linking Species and Ecosystems.* (Eds CG Jones and JH Lawton) pp. 72–83. Chapman and Hall, New York.

Hutchinson K, King K (1982) Microbial respiration in a temperature sown grassland grazed by sheep. *Journal of Applied Ecology* **19**, 821–833. doi:10.2307/2403285.

Huwer RK, Briese DT, Dowling PM, Kemp DR, Lonsdale WM, Michalk DL, Neave MJ, Sheppard AW, Woodburn TL (2005) Can an integrated management approach provide a basis for long-term prevention of weed dominance in Australian pasture systems? *Weed Research* **45**, 175–192. doi:10.1111/j.1365-3180.2005.00452.x.

Hyder MW, Gordon DJ, Tanaka K (2004) Lifetime Wool 2. Pasture growth, utilisation and ewe stocking rate. In *Proceedings of the 25th Biennial Conference of the Australian Society of Animal Production,* 4–8 July, Melbourne, p. 265. Australian Society of Animal Production, Melbourne.

Johnson IR, Chapman DF, Snow VO, Eckard RJ, Parsons AJ, Lambert MG, Cullen BR (2008) DairyMod and EcoMod: biophysical pasture-simulation models for Australia and New Zealand. *Australian Journal of Experimental Agriculture* **48**, 621–631. doi:10.1071/EA07133.

Johnston WH (1996) The place of C_4 grasses in temperate pastures in Australia. *New Zealand Journal of Agricultural Research* **39**, 527–540. doi:10.1080/00288233.1996.9513213.

Johnston PW, McKeon GM, Day KA (1996) Objective 'safe' grazing capacities for south-west Queensland Australia: development of a model for individual properties. *Rangeland Journal* **18**, 244–258. doi:10.1071/RJ9960244.

Jones C (2000) Grazing management for healthy soils. In *Proceedings of the Stipa Inaugural National Grasslands Conference: Better Pastures Naturally,*. Mudgee, NSW, pp. 68–75.

Jones R (2006) *Weeds Wipe 15% off the Value of Livestock Commodities.* <http://www.dpi.nsw.gov.au/research/updates/issues/august-2006/weeds-wipe-15-percent-off-livestock-commodities-value>.

Jones C (2007) Building soil carbon with yearlong green farming. *Evergreen Farming* September, 4–5.

Jones C (2009) Mycorrhizal fungi: powerhouse of the soil. *Evergreen Farming* September, 4–5.

Kahn L (2005) Strategic optimisation of nutrition in Merino sheep meat production systems. Report. Meat and Livestock Australia, Sydney.

Kahn L, Earl J (2005) *Pasture Management Checklist for the Northern Tablelands of NSW.* University of New England, Armidale.

Kahn L, Earl J (2005a) Rangeland Grazing Project. Report to Northern Rivers Catchment Management Authority, NSW.

Kahn L, Earl J (2012) *Pasture and Grazing Management Workshop Manual*. 4th edn. University of New England, Armidale.

Kahn L, Kelly R (2006) 21st Century grazing at Guyra. MLA Prograzier 01–2006.

Kahn LP, Earl JM, Nicholls M (2010) Herbage mass thresholds rather than plant phenology are a more useful cue for grazing management decisions in the mid-north region of South Australia. *Rangeland Journal* **32**, 379–388. doi:10.1071/RJ10003.

Kemp DR, Dowling PM (2000) Towards sustainable temperate perennial pastures. *Australian Journal of Experimental Agriculture* **40**, 125–132. doi:10.1071/EA98003.

Kemp DR, Michalk DL (1994) Introduction. In *Pasture Management Technology for the 21st Century.* (Eds DR Kemp and DL Michalk) pp. ix–xi. CSIRO Publishing, Melbourne.

Kemp DR, Dowling PM, Michalk DL (1996) Managing the composition of native and naturalised pastures with grazing. *New Zealand Journal of Agricultural Research* **39**, 569–578. d oi:10.1080/00288233.1996.9513216.

Killham K (1994) *Soil Ecology.* Cambridge University Press, Cambridge.

Lankester A (2013) Understanding producers' change to more sustainable grazing practices in the tropical savanna rangelands of North Queensland. Final Report B.NBP.0467. Meat and Livestock Australia, Sydney.

Larcher W (1995) *Physiological Plant Ecology*. Springer-Verlag, Berlin.

Lee JM, Donaghy DJ, Roche JR (2008) Effect of defoliation severity on regrowth and nutritive value of perennial ryegrass dominant swards. *Agronomy Journal* **100**, 308–314. doi:10.2134/agrojnl2007.0099.

Lemaire G, Chapman D (1996) Tissue flows in grazed plant communities. In *The Ecology and Management of Grazing Systems*. (Eds J Hodgson and AW Illius) pp. 3–36. CAB International, Oxen, UK.

Lodge G, Whalley RDB (1989) Native and natural pastures on the Northern Slopes and Tablelands of New South Wales. Technical Bulletin 35. NSW Agriculture and Fisheries, Sydney.

Lodge G, Murphy SR, Harden S (2003) Effects of grazing and management on herbage mass, persistence, animal production and soil water content of native pastures. 1. A redgrass-wallaby grass pasture, Barraba, North West Slopes, New South Wales. *Australian Journal of Experimental Agriculture* **43**, 875–890. doi:10.1071/EA02188.

Lodge G, Johnson IR, McCormick L (2012) Pasture utilisation: a key driver for profitable grazing. In *Proceedings of the 27th Annual Conference of the Grassland Society of NSW*. 24–26 July, Wagga Wagga, pp. 116–119. Grassland Society of NSW, Wagga Wagga.

Macgregor AN (1994) Beneficial biota in organic and alternate farming systems. In *Soil Biota*. (Eds CE Pankhurst, BM Doube, VVSR Gupta and PR Grace) pp. 204–208. CSIRO Publishing, Melbourne.

MacLeod ND, McIvor JG (2006) Reconciling economic and ecological conflicts for sustained management of grazing lands. *Ecological Economics* **56**, 386–401. doi:10.1016/j.ecolecon.2005.09.016.

Mason WK, Kay G (2000) Temperate pastures sustainability key program: an overview. *Australian Journal of Experimental Agriculture* **40**, 121–123. doi:10.1071/EA98002.

Maynard B (2013) *Cropping for a Changing Climate*. <http://www.pasturecropping.com>.

McArdle SL, Nadolny C, Sindel BM (2004) Invasion of native vegetation by coolatai grass *Hyparrhenia hirta*: impacts on native vegetation and management implications. *Pacific Conservation Biology* **10**, 49–56.

McCosker T (2000) Cell grazing: the first 10 years in Australia. *Tropical Grasslands* **34**, 207–218.

McCosker T, McLean D, Holmes P (2010) Northern beef situation analysis 2000. Final report B.NBP.0518. Meat and Livestock Australia, Sydney.

McDonald W, Orchard P (1985) *How to Use Dry Sheep Equivalents (DSEs) to Compare Beef Enterprises*. <http://www.dpi.nsw.gov.au/agriculture/farm-business/budgets/livestock/beef/info/dse>.

McEachern S, Francis J, Brown D (2012) Beef production. *AgInsights* **14**, 34–40.

McIvor J, Bray S, Grice T, Hunt L (2010) Grazing management guidelines for northern Australia: scientific rationale and justification. In Enhancing adoption of improved grazing and fire management practices in northern Australia: synthesis of research and identification of best bet management guidelines'. Final report B.NBP.0579. Meat and Livestock Australia, Sydney.

McKeon GM, Hall WB, Crimp SJ, Howell SM, Stone RC, Jones DA (1998) Climate change in Queensland grazing lands. I Approaches and climatic trends. *Rangeland Journal* **20**, 151–176. doi:10.1071/RJ9980151.

McKeon GM, Stone GS, Syktus JI, Carter JO, Flood NR, Ahrens DG, Bruget DN, Chilcott CR, Cobon DH, Cowley RA, Crimp SJ, Fraser GW, Howden SM, Johnston PW, Ryan JG, Stokes CJ, Day KA (2009) Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. *Rangeland Journal* **31**, 1–29. doi:10.1071/RJ08068.

McNaughton SJ (1983) Compensatory plant growth as a response to herbivory. *Oikos* **40**, 329–336. doi:10.2307/3544305.

Medina-Roldan E, Bardgett RD (2011) Plant and soil responses to defoliation: a comparative study of grass species with contrasting life history strategies. *Plant and Soil* **344**, 377–388. doi:10.1007/s11104-011-0756-4.

Millar GD, Badgery WB (2009) Pasture cropping: a new approach to integrate crop and livestock farming systems. *Animal Production Science* **49**, 777–787. doi:10.1071/AN09017.

MLA (2004) *More Beef from Pastures. Module 4: Pasture utilisation*. <http://www.mla.com.au/research-and-development/extension-and-training/more-beef-from-pastures>.

MLA (2012) *Cattle*. <http://www.mla.com.au/About-the-red-meat-industry/Industry-overview/Cattle>.

MLA (2012a) *Pasture Picker*. <http://www.mla.com.au/News-and-resources/Tools-and-calculators/Pasture-picker>.

MLA (2012b) *Pasture Improvement Calculator*. <http://www.mla.com.au/News-and-resources/Tools-and-calculators/Pasture-improvement-calculator>.

Morley FHW, Daniel G (1992) Drought, stocking rate and soil loss. In *Animal Production in Australia: Proceedings of the 19th Biennial Conference of the Australian Society of Animal Production* **19**, 323–325.

Morris GD (2004) Sustaining natural water supplies by understanding the dynamic capacity that humus has to increase soil water holding capacity. Masters thesis. University of Sydney.

Murphy DV, Cookson WR, Braimbridge M, Marschner P, Jones DL, Stockdale EA, Abbott LK (2011) Relationships between soil organic matter and the soil microbial biomass (size, functional diversity, and community structure) in crop and pasture systems in a semi-arid environment. *Soil Research* **49**, 582–594. doi:10.1071/SR11203.

Neumann G, Romheld V (2000) The release of root exudates as affected by plant physiological status. In *The Rhizosphere: Biochemistry and Organic Substances at the Soil-Plant Interface*. (Eds R Pinton, Z Varanini and Z Nannipieri). Marcel Dekker.

Nichols PGH, Loi A, Nutt BJ, Evans PM, Craig AD, Pengelly BC, Dear BS, Lloyd DL, Revell CK, Nair RM, Ewing MA, Howieson JG, Auricht GA, Howie JH, Sandral GA, Carr SJ, de Koning CT, Hackney BF, Crocker GJ, Snowball R, Hughes SJ, Hall EJ, Forster KJ, Skinner PW, Barbetti MJ, You MP (2007) New annual and short-lived perennial pasture legumes for Australian agriculture: 15 years of revolution. *Field Crops Research* **104**, 10–23. doi:10.1016/j.fcr.2007.03.016.

Nichols PGH, Revell CK, Humphries AW, Howie JH, Hall EJ, Sandral GA, Chamkhar K, Harris CA (2012) Temperate pasture legumes in Australia: their history, current use, and future prospects. *Crop and Pasture Science* **63**, 691–725. doi:10.1071/CP12194.

Nie ZN, Zollinger RP, Jacobs JL (2009) Performance of 7 Australian native grasses from temperate zones under a range of cutting and fertiliser regimes. *Crop and Pasture Science* **60**, 943–953. doi:10.1071/CP09067.

Nie ZN, Zollinger RP (2012) Impact of deferred grazing and fertilizer on plant population density, ground cover and soil moisture of native pastures in steep hill country of southern Australia. *Grass and Forage Science* **67**, 231–242. doi:10.1111/j.1365-2494.2011.00838.x.

Norton BE (1998) The application of grazing management to increase sustainable livestock production: The McClymont Lecture. In *Animal Production in Australia: Proceedings of the 22nd Biennial Conference of the Australian Society of Animal Production*, pp. 15–26. Australian Society of Animal Production, Armidale, NSW.

O'Connor TG (1992) Patterns of plant selection by grazing cattle in two savanna grasslands: a plant's eye view. *Journal of the Grassland Society of Southern Africa* **9**, 97–104. doi:10.1080/02566702.1992.9648307.

O'Reagain P, Bushell J, Holloway C (2007) 'esting and developing principles and management guidelines for the sustainable management of the seasonably variable tropical savannas. Final Report NBP.318. Meat and Livestock Australia, Sydney.

Orr DM (2005) Effects of stocking rate, legume augmentation, supplements and fire on animal production and stability of native pastures. Final Report NAP 3.207. Meat and Livestock Australia, Sydney.

Orr DM, Phelps DG (2013) Impacts of level of utilisation by grazing on an *Astrebla* (Mitchell grass) grassland in northwestern Queensland between 1984 and 2010. 1. Herbage mass and population dynamics of *Astrebla* spp. *Rangeland Journal* **35**, 1–15. doi:10.1071/RJ11068.

Orr DM, Yee MC, Myles DJ, Hall TJ, Hilder TB, Connelly PT, Nelson BS (2005) Increasing uptake of drought management options to optimise pasture recovery following drought. Final Report NBP.328. Meat and Livestock Australia, Sydney.

Owen DF (1980) How plants may benefit from the animals that eat them. *Oikos* **35**, 230–235. doi:10.2307/3544430.

Owen DF, Weigert RG (1981) Mutualism between grasses and grazers: an evolutionary hypothesis. *Oikos* **36**, 376–378. doi:10.2307/3544637.

Parsons AJ, Chapman DF (2000) The principles of pasture growth and utilization. In *Grass: Its Production and Utilization*. (Ed. A Hopkins) pp. 31–89. Blackwell Science, Oxford.

Paynter G (2006) Drought: myth and reality. *Australian Organic Journal*, Autumn, 36–37.

Peck G, Buck S, Hoffman A, Holloway C, Johnson B, Lawrence D, Paton C (2011) Review of productivity decline in sown grass pastures. Final Report B.NBP.0624. Meat and Livestock Australia, Sydney.

Porqueddu C, Maltoni S, McIvor JG (2005) Strategies to mitigate seasonality of production in grassland based systems. In *Grasslands: A Global Resource* (Ed. DA McGilloway). Wageningen Academic, The Netherlands.

Pratley JE, Virgona JM (2010) Pasture management. In *The International Sheep and Wool Handbook*. (Ed. D Cottle) pp. 437–456. Nottingham University Press, Nottingham.

Pringle MJ, Allen DE, Dalal RC, Payne JE, Mayer DG, O'Reagain P, Marchant BP (2011) Soil carbon stock in the tropical rangelands of Australia: effects of soil type and grazing pressure, and determination of sampling requirement. *Geoderma* **167**, 261–273. doi:10.1016/j.geoderma.2011.09.001.

Probo M, Massolo A, Lonati M, Bailey DW, Gorlier A, Maurino L, Lombardi G (2013) Use of mineral mix supplements to modify the grazing patterns by cattle for the restoration of sub-alpine and alpine shrub-encroached grasslands. *Rangeland Journal* **35**, 85–93. doi:10.1071/RJ12108.

Quirk M (2010) Priorities for investment in sown pastures for the beef indisutry of northern Australia. Final Report B.NBP.0652. Meat and Livestock Australia, Sydney.

Reeves I, Thompson LJ (2005) *Integrated Parasite Management in Sheep Project Benchmark Survey*. Australian Wool Innovation. <www.wool.com/Grow_Animal-Health_Integrated-Parasite-Management_Integrated-Parasite-Management-sheep_IPM-s- National-Survey.htm>.

Richards JH (1993) Physiology of plants recovering from defoliation. In *Proceedings of the 17th International Grasslands Congress*. Palmerston North, New Zealand, pp. 85–94.

Ridley AM, White RE, Helyar KR, Morrison GR, Heng LK, Fisher R (2001) Nitrate leaching loss under annual and perennial pastures with and without lime on a duplex (texture contrast) soil in humid southeastern Australia. *European Journal of Soil Science* **52**, 237–252. doi:10.1046/j.1365-2389.2001.00387.x.

Robinson GG, Archer KA (1988) Agronomic potential of native grass species on the Northern Tablelands of New South Wales. I. Growth and herbage production. *Australian Journal of Agricultural Research* **39**, 415–423. doi:10.1071/AR9880415.

Rook AJ, Dumont B, Isselstein J, Osoro K, Wallis DeVries MF, Parente G, Mills J (2004) Matching type of livestock to desired biodiversity outcomes in pastures: a review. *Biological Conservation* **119**, 137–150. doi:10.1016/j.biocon.2003.11.010.

Sanford P, Whalley RDB, Garden DL, Norton MR, Waters CM, Smith AB, Mitchell ML, Kobelt E, Friend DA, Hall E, Auricht G (2005) Identification of superior native and introduced grasses for low input pastures in temperate Australia. *Rangeland Journal* **27**, 55–71. doi:10.1071/RJ05005.

Savory A (1999) *Holistic Management: A New Framework for Decision Making*. Island Press, Washington.

Sayer J, Cassman KG (2013) Agricultural innovation to protect the environment. *Proceedings of the National Academy of Sciences of the USA* **110**, 8345–8348. doi:10.1073/pnas.1208054110.

Scott J (1997) Pasture establishment. In *Pasture Production and Management*. (Eds JV Lovett and JM Scott) pp. 171–190. Inkata Press, Melbourne.

Scott KA, Setterfield SA, Douglas MM, Anderson AN (2010) Environmental factors influencing the establishment, height and fecundity of the annual grass *Sorghum intrans* in an Australian tropical savanna. *Journal of Tropical Ecology* **26**, 313–322. doi:10.1017/S0266467409990629.

Scrivner JH, Center DM, Jones MB (1986) A rising plate meter for estimating production and utilization. *Journal of Range Management* **39**, 475–477. doi:10.2307/3899458.

Seis C (2004) Pasture cropping: a land management technique. *Stipa Native Grasslands Newsletter* **27**, 6–8.

Seligman N (1996) Management of Mediterranean grasslands. In *The Ecology and Management of Grazing Systems.* (Eds J Hodgson and AW Ilius) pp. 359–391. CAB International, Wallingford, UK.

Simpson P, Langford C (1996) *Managing High Rainfall Native Pastures on a Whole Farm Basis.* NSW Agriculture.

Simpson RJ, Dove H, Moore AD (1998) Efficient nutrient use. In *Animal Production in Australia: Proceedings of the 22nd Biennial Conference of the Australian Society of Animal Production,* pp. 69–70. Australian Society of Animal Production, Armidale, NSW.

Sinden J, Jones R, Hester S, Odom D, Kalisch C, James R, Cacho O (2004) The economic impact of weeds in Australia. Technical Series No. 8. CRC for Australian Weed Management.

Singh RS, Srivastava SC, Raghubanashi AS, Singh JS, Singh SP (1991) Microbial C, N and P in dry tropical savanna: effects of burning and grazing. *Journal of Applied Ecology* **28**, 869–878. doi:10.2307/2404213.

Stafford Smith DM (1996) Management of rangelands: paradigms at their limits. In *The Ecology and Management of Grazing Systems.* (Eds J Hodgson and AW Ilius) pp. 325–357. CAB International, Wallingford, UK.

Stafford Smith DM, McKeon GM, Watson IW, Henry BK, Stone GS, Hall WB, Howden MS (2007) Learning from episodes of degradation and recovery in variable Australian rangelands. *Proceedings of the National Academy of Sciences of the USA* **104**, 20690–20695. doi:10.1073/pnas.0704837104.

Stokes C, Marshall N, Macleod N (2012) Developing improved industry strategies and policies to assist beef enterprises across northern Australia adapt to a changing and more variable climate. Final Report B.NBP.0617. Meat and Livestock Australia, Sydney.

Stone GS, Fraser GW, O'Reagain PJ, Timmers PK, Bushell JJ (2008) A new methodology for the calculation of pasture utilisation for grazing lands. In *Proceedings of the Australian Rangeland Society Conference,* Charters Towers, Qld.

Tainton NM, Morris CD, Hardy MB (1996) Complexity and stability in grazing systems. In *The Ecology and Management of Grazing Systems.* (Eds J Hodgson and AW Ilius) pp. 275–299. CAB International, Wallingford, UK.

Tomkins NW, O'Reagain PJ, Swain D, Bishop-Hurley G, Charmley E (2009) Determining the effect of stocking rate on the spatial distribution of cattle for the subtropical savannas. *Rangeland Journal* **31**, 267–276. doi:10.1071/RJ07070.

Tothill JC, Gillies C (1992) *The Pasture Lands of Northern Australia: Their Condition, Productivity, and Sustainability.* Occasional Publication No. 5. Tropical Grassland Society of Australia, Brisbane.

Tozer KN, Chapman DF, Quigley PE, Dowling PM, Cousens RD, Kearney GA, Sedcole JR (2008) Controlling invasive annual grasses in grazed pastures: population dynamics and critical gap sizes. *Journal of Applied Ecology* **45**, 1152–1159. doi:10.1111/j.1365-2664.2008.01500.x.

Trotter M (2007) Best practice management of pasture weeds in southern Australia. PhD thesis. University of New England, Armidale.

Trotter MG, Lamb DW, Donald GE, Schneider DA (2010) Evaluating an active optical sensor for quantifying and mapping green herbage mass and growth in a perennial grass pasture. *Crop and Pasture Science* **61**, 389–398. doi:10.1071/CP10019.

Troughton A (1957) *The Underground Organs of Herbage Grasses*. Commonwealth Agricultural Bureau, UK.

Turner CL, Seastedt TR, Dyer MI (1993) Maximization of aboveground grassland production: the role of defoliation frequency, intensity, and history. *Ecological Applications* **3**, 175–186. doi:10.2307/1941800.

Voison A (1959) *Grass Productivity.* Crosby Lockwood and Son, London.

Welker JM, Rykiel EJ, Briske DD, Goeschl JD (1985) Carbon input among vegetative tillers within two bunchgrasses: assessment with carbon^{11} labelling. *Oecologia* **24**, 330–334.

Westoby M, Walker B, Noy-Meir I (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **42**, 266–274. doi:10.2307/3899492.

Whalley RDB (1994) State and transition models for grasslands. 1. Successional theory and vegetation change. *Tropical Grasslands* **28**, 195–205.

Whalley RDB, Belloti W (1997) Natural pastures and rangelands. In *Pasture Production and Management.* (Eds JV Lovett and JM Scott) pp. 171–190. Inkata Press, Melbourne.

Whalley RDB, Robinson GG, Taylor JA (1978) General effects of management and grazing by domestic livestock on the rangelands of the Northern Tablelands of New South Wales. *Australian Rangeland Journal* **1**, 174–190. doi:10.1071/RJ9780174.

Wheeler DJB, Jacobs SWL, Whalley RDB (2002) *Grasses of NSW*. 3rd edn. University of New England, Armidale.

Williams J, Hook RA (1998) Livestock management for catchment care: what role quality assurance? Wyndham Lecture. In *Animal Production in Australia: Proceedings of the 22nd Biennial Conference of the Australian Society of Animal Production*. Australian Society of Animal Production, Armidale, NSW.

Wilson AD, Simpson RJ (1994) The pasture resource base: status and issues. In *Pasture Management Technology for the 21st Century.* (Eds DR Kemp and DL Michalk) pp. 1–25. CSIRO Publishing, Melbourne.

Wilson AD, Harrington GN, Beale IF (1990) Grazing management. In *Management of Australia's Rangelands.* (Eds GN Harrington, AD Wilson and MD Young) pp. 129–139. CSIRO Publishing, Melbourne.

Wolfe EC (2010) *FAO Country Pasture Profiles: Australia*. <http://www.fao.org/ag/AGP/AGPC/doc/Counprof?Australia/australia.htm>.

Wolfe EC, Dear BS (2001) The population dynamics of pastures, with particular reference to southern Australia. In *Competition and Succession in Pastures* (Eds PG Tow and A Lazenby) pp. 119–148. CAB International, Wallingford, UK.

Wylie P (2007) Economics of pastures versus grain or forage crops. *Tropical Grasslands* **41**, 229–233.

Young R, Wilson BR, McLeod M, Alston C (2005) Carbon storage in the soils and vegetation of contrasting land uses in northern New South Wales, Australia. *Australian Journal of Soil Research* **43**, 21–31. doi:10.1071/SR04032.

Young SL, Kyser GB, Barney JN, Claassen VP, DiTomaso JM (2011) The role of light and soil moisture in plant community resistance to invasion by yellow starthistle (*Centaurea solstitialis*). *Restoration Ecology* **19**, 599–606. doi:10.1111/j.1526-100X.2010.00686.x.

Younger VB (1972) Physiology of defoliation and regrowth. In *The Biology and Utilization of Grasses*. (Eds VB Younger and CM McKell) pp. 292–304. Academic Press, New York.

16 Growing and finishing beef cattle at pasture and in feedlots

P.I. Hynd

INTRODUCTION

The term 'finishing' applied to beef production refers to the growing of animals to a desired end-point, usually defined on the basis of a combination of liveweight, carcass weight, degree of subcutaneous fat cover, and degree of marbling (intramuscular fat) of the meat. Increasingly it will include components related to eating quality of beef, such as glycogen levels in muscles at slaughter and ultimate pH of meat. Achieving rapid and efficient growth is a target of finishing systems because feed costs represent a high proportion of the total costs of production (Chapters 11, 18). To maximise growth and efficiency, stock feeds must contain high levels of readily fermentable carbohydrates, sufficient rumen-degradable protein to supply the microbes with a nitrogen source, a minimum level of undegraded dietary protein, containing an appropriate balance of essential amino acids, essential mineral elements in correct proportions, adequate levels of vitamins A, D and E, and an optimum level of neutral detergent fibre (NDF) to ensure balanced rumen function. The most cost-effective means of achieving this is via pasture-based systems (MLA 2004). Forages provide energy and the essential nutrients at approximately half the cost of grain-based feedlot rations, and opportunities exist to further improve forage utilisation by reducing pasture wastage, optimising grazing pressure and maximising plant growth rate (Chapter 15). Seasonal variations in pasture growth rates and forage quality restrict the periods in which cattle can be finished in most regions of Australia. Maximising voluntary intake (to approx. 3% of bodyweight) of both pasture and concentrates is desirable in finishing systems. For typical finishing rations with a metabolisable energy (ME) content of more than 10 MJ/kg dry matter (DM), feed intake in healthy animals is regulated largely by energy demand and not gut fill. Increasing the NDF content of such feeds has the advantage of stabilising rumen fermentation, reducing the incidence of subacute and acute ruminal acidosis, and maximising intake. Intake regulation in cattle on finishing rations is achieved largely through post-absorptive signals from hepatic oxidation of absorbed nutrients, which signals satiety centres in the brain via the vagus nerve. Propionate seems to be the most powerful satiety-signalling molecule (Quigley and Heitmann 1995). Nutritional diseases in feedlots include lactic acidosis, subacute ruminal acidosis, polioencephalomalacia, urolithiasis, grain bloat, hypocalcaemia and hypomagnesaemia. Cattle on high-quality forages are susceptible to legume or pasture bloat, and nitrate poisoning. There are also several anti-nutritive factors present in pasture plants. Finishing cattle at pasture often requires supplementary feeding. The most cost-effective supplements to achieve rapid growth on otherwise high-quality pastures are often those which correct a limiting nutrient deficiency (e.g. an essential micronutrient), thereby increasing voluntary intake and efficiency of growth. Energy supplements often reduce pasture intake, thereby reducing the effectiveness of supplementation, although the extent of this substitution effect varies depending on the base forage and the supplement (Minson 1990). Maximising the efficiency of gain in finishing beef cattle systems will become increasingly important as competition for high-energy grains, competition from high-value alternative uses of high-rainfall land, and demands for reduced

Table 16.1: ME requirements (MJ/day) of growing beef cattle of medium mature size on a ration containing 12 MJ/kg DM

Liveweight (kg)	Liveweight gain (kg/day)			
	0.20	0.50	1.00	1.50
100	20	25	*38*	*66*
200	31	38	56	*89*
300	41	50	73	*112*
400	50	60	88	*135*
500	58	70	102	156
600	66	79	115	176

Values in italic indicate rates of gain unlikely to be achieved (based on estimates of maximum DM intakes).
Source: Adapted from ARC (1980).

greenhouse gas emissions per unit of beef product, increase (Chapter 18). Increasing the efficiency of pasture-based cattle production systems will continue to be a high priority for Australian beef producers.

NUTRIENT REQUIREMENTS OF FINISHING BEEF CATTLE

ME requirements of finishing beef cattle

Feed costs in cattle finishing operations account for a high proportion of the total variable costs and therefore the gross margin of the enterprises. For example, feed accounts for 60–70% of feedlot finishing costs (Chapters 11, 18). For this reason, the time on feed to meet market specifications is often the critical determinant of profitability. Table 16.1 shows the energy requirements of growing beef cattle on a typical finishing ration containing 12 MJ ME/kg DM. High intakes of energy and faster growth are more efficient because the obligate maintenance energy requirement forms a smaller proportion of the total energy intake. To achieve high rates of gain, a combination of high energy density and high voluntary DMI are required (discussed later in this chapter).

Typical rations and feedstuffs which are available for inclusion in rations for finishing cattle are listed in Table 16.2.

The risks of acidosis and subacute ruminal acidosis increase with the level of rapidly fermentable starch. For the cereal grains the risks decrease from wheat to barley to oats, and for the pulses from beans to peas to lupins.

Protein requirements of finishing beef cattle

The protein requirements of beef cattle include the protein-nitrogen required from the breakdown of proteins in the rumen to supply the microbes with nitrogenous building blocks (rumen-degradable protein, RDP) and protein which escapes rumen degradation due to chemical or physical resistance to ruminal proteases (bypass or protected or undegraded dietary protein, UDP). Figure 16.1 shows the flow of nitrogenous substances through the digestive tract of ruminants. The processes involved in these nitrogenous transactions are reviewed by several authors (Clark *et al.* 1992; AFRC 1992; Bach *et al.* 2005).

Ruminants are uniquely placed in the animal kingdom in being able to produce a significant quantity of protein from non-protein nitrogen sources through the action of the microbial population resident in the reticulorumen and omasum. Non-protein nitrogen sources include amino acids, nitrogenous lipids, amines, amides, nitrates, purines, pyrimidines, alkaloids and members of the vitamin B group complex (Clark *et al.* 2005). Cell-bound, mixed microbial proteases produced by consortia of bacteria attached to the feed particles, degrade the proteins and release a mixture of amino acids and peptides. The rate and extent of this degradation depends on the microbes present and the accessibility and susceptibility of the proteins to proteolysis. The latter depends on a combination of the solubility of the protein and its chemical structure (Yang and Russell 1992). The breakdown products of this activity are simple peptides, amino acids or ammonia and these are incorporated into microbial protein by the anaerobic bacteria, ciliated protozoans and fungi. The nature of the proteins in forages and concentrates fed to beef cattle differ widely in their degradability and therefore their ability to meet the UDP requirements of rapidly growing young cattle (Table 16.3).

The energy for the breakdown of proteins and their incorporation into microbial protein is derived from the breakdown of complex carbohydrates and lipids to simple short-chain volatile fatty acids. The diet of growing and finishing cattle must contain sufficient rumen-digestible energy to allow the surplus ammonia to be incorporated into microbial protein, otherwise it is lost as urea in the urine (although some will be recycled to the reticulorumen via the saliva). The fate of the microbial protein then depends on the fate of the microbes themselves. They may be recycled within the rumen through the RDP pool or they may exit the rumen via the reticulo-omasal orifice. On entry to the abomasum the microbes are degraded by proteolytic enzymes and the microbial amino acids are absorbed from the small intestine. The total available amino acids entering the portal system are known collectively as 'metabolisable protein'.

The protein requirements of growing and finishing beef cattle are shown in Table 16.3.

Table 16.2: ME density, crude protein content (and range of CP), and undegradable dietary protein (UDP) as a proportion of total crude protein content, of typical feedstuffs and pastures available for finishing beef cattle

Feedstuff	Metabolisable energy density (MJ/kg DM)[1]	Crude protein (% DM)	UDP (% CP)	Comments
Grains and seeds				
Barley	13.7	12.0 (8.0–18.0)	50	Medium–high risk acidosis Low calcium levels
Wheat	14.0	13.0 (12–14)	35	High risk acidosis Low calcium levels
Oats	11.5	10.0 (6–13)	56	Low risk acidosis
Triticale	13.4	13.1 (8–19)	32	
Lupins	13.2	33.0 (28–40)	25	Low risk acidosis Uraemia risk
Maize grain	13.5	9.5 (6–12)	62	
Field peas	13.4	24.0 (20–27)	16	Low risk acidosis
Beans (faba)	12.8	26	10	Low risk acidosis
Canola meal	11.4	39.0 (33–43)	30	Glucosinylates may reduce palatability
Cottonseed meal	10.3	32.0 (37–47)	30–40	
Soybean meal	13.0	52.0 (46–59)	37	
Sorghum	11.0	11.0 (6–15)	68	
Whole cottonseed	13.0–15.0	22.4 (20–23)	30	Potential negative effects of gossypol; low risk acidosis
Copra meal	11.0	18.0	20	Potential rancidity and reduced palatability
Pasture				
Early grass dominant	11.2	24.6	38	High risk grass tetany, nitrate poisoning
Legume dominant	11.5	26.3 (21–31)	30	High risk bloat
Hays[1]				
Oaten early	9.0	8.5 (6–11)	36	Insufficient ME;
Oaten late (ripe seed)	8.1	5.4	30	NDF source
Pasture grass	9.1	9.1 (2.0–18.9)	30	NDF source Insufficient ME,
Pasture legume	10.2	21.3 (19–24)	29	low CP, low UDP, good source of NDF
Lucerne	10.1	21.0 (11.1–30.1)	30	
Cereal straws	5.9	3.7 (2.9–4.4)	10	
Silage[1]				
Legume	10.0	21.4 (18–24)	25	Potential unpalatability
Grass	8.4	15.2 (11–19)	30	Potential unpalatability Insufficient ME
Molasses	11.0 (10–12)	4.0 (2–6)		Toxicity above 25% of diet

[1] These values are approximate only and represent typical values for each feedstuff. ME, CP and UDP values will vary with intake level, feedstuff composition, and processing (e.g. pelleting).

General comments about the use of each feedstuff are included.

Source: A Pullman and AD Hughes (pers. comm.).

Mineral requirements of finishing beef cattle

Beef cattle require 17 mineral elements (10 microminerals and seven macrominerals) in order to thrive. The macrominerals are calcium, phosphorus, magnesium, potassium, sodium, chlorine and sulphur and these are largely components of structural tissues and buffering systems. The microminerals are copper, cobalt, chromium, iodine, iron, manganese, molybdenum, nickel, selenium and zinc, and are largely present as components of enzymes or as special components of important molecules such as haemoglobin (iron), thyroid hormones (iodine) or vitamin B12 (cobalt). A deficiency of any one element or an imbalance of minerals, results in reduced voluntary intake, reduced efficiency of growth, general ill-thrift and specific symptoms characteristic of each element (Underwood 1981). The micromineral and macromineral requirements of growing and finishing beef cattle are listed in Table 16.4.

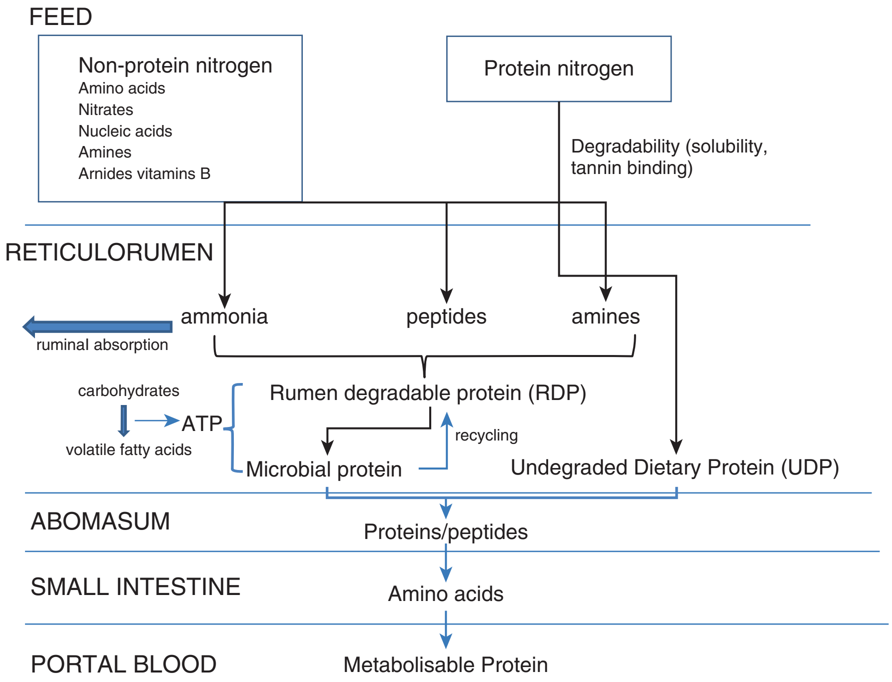


Figure 16.1: Flow of nitrogenous substances in the digestive tract of beef cattle from feed to absorbed nutrients available for systemic metabolism. The 'quality' of a feed protein is a function of its ability to supply microbes with peptides, amino acids and ammonia at a rate commensurate with the supply of fermentable energy, and its content of UDP containing the amino acids which are limiting growth (usually methionine, lysine, threonine and tryptophan). Source: Adapted from AFRC (1992); Clark *et al.* (1992); Bach *et al.* (2005).

Calcium and magnesium in finishing beef cattle

Calcium and magnesium are two of the elements most commonly limiting growth in beef finishing systems, as grass forages and concentrate rations are low in magnesium and calcium respectively. The calcium content of cereal grain rations for feedlot cattle is 0.02–0.08%, well below the requirement of 0.36–0.6% for growth (Table 16.3). In contrast to dairy cows, in which parturient paresis (milk fever) is the common outcome of low calcium intake, coupled with high calcium output in milk and inability to rapidly mobilise body reserves, the more common form of hypocalcaemia in beef cattle is non-parturient. The symptoms are hyperaesthesia and tetany associated with stress and exertion, rather than the flaccid paralysis more common in hypocalcaemic dairy cows. Grass tetany is only a problem in southern Australia where C3 winter-dominant pastures are low in magnesium and where uptake of magnesium from the gut is reduced by a complex interaction between magnesium, rapidly degraded protein and potassium (Suttle and Field 1969)

Table 16.3: Protein requirements (RDP and UDP in g/day) of cattle at different liveweights and growing at different rates, assuming the ME content of the diet is ~11 MJ/kg DM

		Liveweight gain (kg/day)			
Liveweight (kg)	Form of protein	0.25	0.50	1.00	1.50
100	RDP	160	185	235	310
	UDP	35	105	230	310
200	RDP	255	285	360	460
	UDP	0	35	130	180
300	RDP	335	375	465	595
	UDP	0	0	35	60
400	RDP	410	455	565	720
	UDP	0	0	0	0
500	RDP	475	530	660	835
	UDP	0	0	0	0
600	RDP	540	600	745	945
	UDP	0	0	0	0

Values are for bulls of large mature size. Older (heavy) animals usually have no requirement for UDP except for high lactation cows.
Source: ARC (1980).

Copper deficiency in finishing beef cattle

Copper deficiency occurs in cattle grazing spring pastures in southern Australia when soil copper levels are <2.5 ppm. The levels of molybdenum and sulphur in pastures strongly influence copper availability. Symptoms of copper deficiency in cattle include depigmentation of the coat and hair, particularly around the

Table 16.4: Mineral element requirements of growing and finishing beef cattle

Mineral element	Feed content
Trace elements	**(mg/kg DM)**
Cobalt	0.11–0.20
Copper	8–16
Iodine	0.5
Iron	30–50
Manganese	20–25
Selenium	0.10
Zinc	12–35
Macrominerals	**(g/kg DM)**
Phosphorus	1.8–3.2
Sulphur	1.5
Calcium	1.9–4.0
Sodium	0.8–1.2
Magnesium	1.9
Potassium	5.0
Chlorine	2.0

Source: Adapted from ARC (1980).

eyes, and in extreme cases sudden cardiac arrest or 'falling disease'. Growth rates are depressed and anaemia may be apparent. Liver levels are a more reliable indicator, with levels <16 ppm indicating potential copper deficiency. Copper fertilisers, injections or copper oxide needles can supply copper in grazing situations, while drenches, licks and water medications are less reliable or only short-term solutions. There is a genetic difference in predisposition to copper deficiency, with Angus cattle less susceptible to deficiency than Simmental and Charolais (Ward *et al*. 1995).

Phosphorus in finishing beef cattle

Phosphorus is the second most common element in the body of a cow and a deficiency of phosphorus is common, particularly in northern Australia where soil P levels can be <6–8 mg/kg (bicarbonate extraction P). Phosphorus-deficient cattle consume less, probably digest feed less efficiently, and display signs of depraved appetite and bone chewing, poor body condition and broken bones (Ternouth 1990). Supplements containing phosphorus include proprietary P supplements, water-soluble P for water medication, or loose licks.

Cobalt

As for other trace elements, a deficiency of cobalt in the early stages is characterised by inappetence, poor growth or weight loss. If the deficiency continues animals suffer weight loss, fatty liver and anaemia. Decreased appetite and failure to grow or moderate weight loss are early signs of cobalt deficiency. If the deficiency is allowed to become severe, animals exhibit severe unthriftiness, rapid weight loss, fatty degeneration of the liver, and pale skin and mucous membranes as a result of anaemia. Cobalt deficiency has been reported to impair neutrophil function and reduce disease and infection resistance (MacPherson *et al*. 1987).

RELATIVE COSTS OF TYPICAL FEEDSTUFFS AVAILABLE FOR FINISHING BEEF CATTLE

Given that feed costs represent a high proportion of total costs of the finishing enterprise, it is essential that rapid growth is achieved at the least possible cost. Energy is the major component of the ration and is usually 'first-limiting' to growth, so it is logical to minimise the cost of dietary energy in the first instance. For feedlot finishing, the importance of energy costs are readily apparent and are easily calculated as $/MJ ME. For pastures, the costs are less apparent, but nevertheless important. To allow comparison of the costs of pasture energy and protein with those of grain-based rations, either the cost of agistment or capital-based values can be used. Capital-based values depend on land values, interest rates, pasture maintenance costs, DM production rates, utilisation rates of biomass and, of course, the nutritive value of the pasture. Table 16.5 shows how the cost of a kilogram of pasture can be calculated. This value is then applied to a feed conversion ratio to provide an estimate of the cost of

Table 16.5: Estimation of the cost and value of pastures for growing beef cattle

Capital-based cost	Typical values
Land value	$2000/ha
Opportunity cost of land = 1 × interest rate %	$160 ($2000 × 0.08)
Pasture maintenance cost	$20/ha
Annual cost of pasture	$150/ha
DM production	6000 kg/ha
Pasture utilisation rate	45%
DM consumed	6000 × 0.45 = 2700 kg/ha
Feed cost	($160 + $20 + $150)/2700 = $0.12/kg DM consumed
Feed conversion ratio (kg feed DM/kg liveweight gain)	10:1 (kg feed DM:kg liveweight gain)
$/kg liveweight gain	$1.20/kg gain

Source: MLA (2004).

1 kg of liveweight gain at pasture. This can then be compared to the cost of grain-based rations and the feed conversion ratio achievable in feedlots.

This calculation is particularly sensitive to the rate of pasture utilisation and the feed conversion ratio (FCR). The cost of concentrate rations per kg liveweight gain similarly are heavily dependent on FCR and, of course, grain prices. Typical values of FCR (6:1) and ration cost ($300/t) indicate a cost/kg gain of $1.80. Obviously these figures are not indicative of gross margins or indicators of 'profit', return on capital and so on, but they do provide some indication of the biological efficiencies of the two systems of finishing cattle.

As competition for scarce resources increases with global population, global affluence and food demands, efficient utilisation of pastures will become increasingly important. Finishing cattle to specifications of liveweight, fat cover and fat colour on pasture, however, will continue to be a challenge in many regions of Australia given the highly variable feed base (discussed later in this chapter).

FEED INTAKE REGULATION IN BEEF CATTLE ON ENERGY-DENSE RATIONS

Maximising the growth rate of cattle in the finishing phase depends on maximising the total quantity of energy substrates and essential nutrients available for absorption from the gastrointestinal tract, so an understanding of the mechanisms operating to regulate the total quantity of feed consumed per day is important. These mechanisms are complex and include neural, hormonal and metabolite signals which provide the animal with perception of its immediate and long-term metabolic status (Baile and Forbes 1974; Forbes and Barrio 1992; Stubbs 1999; Allen 1996, 2000). This array of peripheral signals is transmitted to anorexigenic (satiety) and orexigenic (hunger) neurons in the arcuate nucleus of the medio-basal hypothalamus, via vagal afferent neurons (Anand and Brobeck 1951). Integration of these signals with higher centres of central processing (memory, experience, social facilitation, neophobia i.e. fear of novel feeds, and neophilia i.e. preference for novel feeds), results in changes in feeding behaviour and voluntary intake. Extensive research has been directed towards identifying the array of peripheral signals, their receptors, location, and triggers in non-ruminants. It is becoming increasingly apparent that similar mechanisms operate in ruminants, although there is the added complexity of rumen fermentation, fermentation products, and site of digestion of fibre and starches (Roche *et al.* 2008). Figure 16.2 summarises the various plant, animal and rumen factors which determine the voluntary intake of a given ration. These are discussed below, with an emphasis on the regulation of voluntary intake of nutrient-dense forages and concentrates in finishing beef cattle.

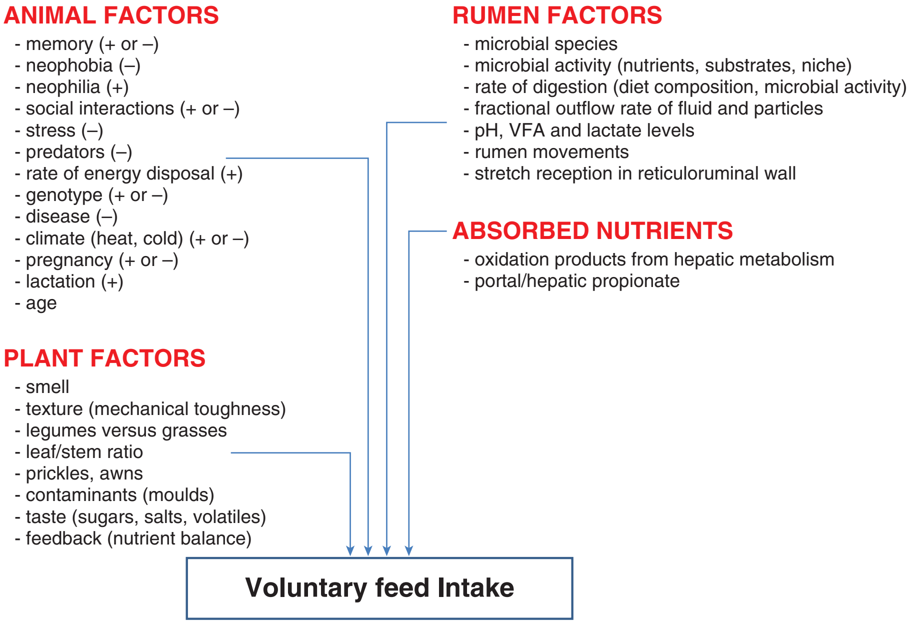


Figure 16.2: Animal, plant, rumen and post-absorptive factors interacting to influence voluntary feed intake in beef cattle on forage and concentrate rations.

Physical factors limiting voluntary feed intake in beef cattle

A positive relationship between the DM digestibility of a diet and voluntary DMI in ruminants has long been considered evidence that intake is limited by physical distension of the gastrointestinal tract (Campling and Balch 1961; Baile and Forbes 1974; Grovum 1987; Forbes 2007). Forages that are slowly digested to a critical minimum size for passage (Poppi *et al*. 1980) remain in the rumen for longer than those more rapidly digested. Physical limitations to voluntary feed intake (VFI) are a result of the time required for chewing or of the stimulation of stretch receptors in the muscle layers surrounding the reticulorumen (Harding and Leek 1972). Addition of inert fill to the reticulorumen reduces VFI as a result of both volume and weight of the ingesta (Schettini *et al*. 1999), but the complex interaction of signalling factors triggering meal cessation means that the distension thresholds vary between animals and within animals differing in physiological state (Allen 2000). Nevertheless, the factors driving rumen fill and therefore VFI are those associated with the rate of flow of material from the rumen. The rate of diminution of particles to a size and density consistent with presentation to the reticulo-omasal orifice (Poppi *et al*. 1980), motility of the reticulorumen, and anatomy and functioning of the reticulo-omasal orifice all contribute to the rate of emptying of the rumen, hence VFI. Rate of particle diminution is related to the mechanical strength of the particles, and their digestibility.

Slowly digested feeds thereby contribute to rumen 'fill' and the maintenance of satiety signals emanating from stimulation of mechanoreceptors embedded in the wall of the reticulorumen (Allen 2000). There is therefore a general positive relationship between forage digestibility and VFI (Blaxter *et al*. 1961; Dinius and Baumgardt 1970), and an associated negative relationship between fibre forage content and VFI (Van Soest 1965). This model works well for rations below ~70% digestibility and containing more than 45% NDF, because rumen fill is the predominant satiety signal that is operating. However, for diets with digestibility >70% (i.e. >10 MJ ME/kg), VFI is regulated more by the energy demand of the animal. In other words, ruminant animals on high-energy diets respond more like non-ruminants in that VFI is negatively associated with the energy content of the diet (Chapter 11). The VFI reflects the energy demands of the animal, so the greater the energy density, the less feed consumed (Fig. 16.3). This figure is based on a wide range of data for beef and dairy cattle on forage and concentrate rations (Lippke 1986; Jung and Allen 1995; Allen 2000; Galyean and Defoor 2003; Arelovich *et al*. 2008; Mertens 2009) and was first proposed by Mertens (2009). The NDF content of the ration is related to VFI by a quadratic or curvilinear relationship because there are two opposing forces operating in the animal. Animals eat to obtain energy, so as NDF increases (and ME density of the feed correspondingly decreases), the animal attempts to eat more feed to meet its energy requirement. In this phase of the curve, DMI increases as NDF increases. However, the second force on intake begins to operate when the NDF content exceeds, and the energy content falls below, a threshold. Beyond this threshold level of NDF, gut fill limits intake (Fig. 16.3). It is important to recognise that despite a declining DMI as the ME exceeds the threshold, total ME intake continues to increase, at least to a point when intake declines to such an extent that total energy intake is compromised.

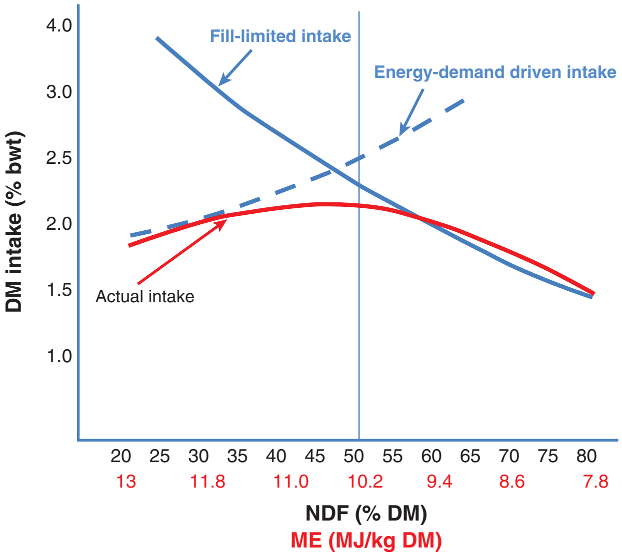


Figure 16.3: Theoretical relationship between dietary NDF (%), ME (MJ/kg DM) and voluntary DM intake (DMI as % bodyweight/day) for cattle. The dashed line is the relationship between NDF (%) and VFI if energy demand is the only factor operating (i.e. higher NDF = lower energy density, so animals eat more to satisfy their energy requirements). The solid blue line represents the relationship between NDF (%) and VFI if physical limitations of the reticulorumen are the only factor operating (i.e. higher NDF = greater 'fill', hence satiety). A quadratic relationship (brown line) occurs because energy demand drives intake up to a point where gut fill begins to limit energy intake. For finishing rations (>10 MJ/kg DM), energy demand is the major driver of VFI. The ME values (MJ/kg DM) in red were derived from NDF using the formula of Boguhn *et al*. (2003). Source Mertens (2009).

While this theoretical relationship would operate for forage-based and grain-based rations, the precise nature of the curve will vary with forage type (legumes vs grasses; Van Soest 1965), C3 vs C4 grasses, digestibility of the NDF (Lippke 1986) and production potential of the cattle (Arelovich *et al.* 2008).

There may be a third factor operating to alter the NDF/intake relationship, and that is the impact of fibre on rumen health and function when diets are low in fibre (i.e. high-soluble carbohydrate forages and grains). Increasing NDF on such rations may stimulate intake by stabilising the rumen pH by increasing saliva flow which provides buffering for ruminal acids.

Factors influencing VFI of high-energy diets by beef cattle

The positive relationship between diet digestibility and VFI only seems to hold for forages up to a digestibility of ~70% (Conrad *et al.* 1964). These authors considered that this is the breakpoint at which intake regulation switches from physical limitation to limitation by satisfaction of energy demand. However, given the multiplicity of positive and negative factors regulating intake, the transition from physical to metabolic regulation of intake is likely to be imprecise. Most ‘finishing rations’ have energy densities of >10 MJ/kg DM (>68% DM digestibility) so non-physical factors are likely to play a major role in regulating the intake of nutrients. Evidence supporting the role of circulating factors in regulating VFI in ruminants, was clearly demonstrated by blood-swapping experiments in which blood from satiated sheep suppressed intake in hungry sheep and blood from hungry sheep increased intake in previously satiated sheep (Seoane *et al.* 1972). Circulating factors possibly similar to those identified in monogastric animals, must be influencing orexigenic and anorexigenic centres in ruminants. In non-ruminants a suite of metabolites (e.g. glucose, amino acids, lipids), gut peptides and hormones are involved in intake regulation (including ghrelin, leptin, cholecystokinin, insulin, pancreatic glucagon, peptide YY_{3-36}, obestatin, endocannabinoids, amylin, pancreatic polypeptide, somatostatin). In ruminants, all of the above, as well as several rumen-related factors (e.g. ruminal pH, osmolarity, acetic, propionic and butyric acids, lactic acid), appear to be involved in intake regulation.

Rumen pH, rumen volatile fatty acids, rumen osmolarity and feed intake

Cattle on typical finishing rations experience wide fluctuations in ruminal production of volatile fatty acids and lactate, ruminal pH and the osmolarity of the rumen fluid, all of which are interrelated and potentially influence VFI. The tonicity of the rumen fluid may also contribute to satiation, as there is a high and negative correlation between rumen fluid osmolality and feed intake (Phillip *et al.* 1981). Intraruminal infusions of hypotonic and hypertonic solutions resulted in reduced or stimulated food intake (Ternouth and Beattie 1971; Bergen 1972). Epithelial receptors sensitive to chemical stimuli have been identified at the level of the basement membrane (Leek 1986) and these appear to respond to stimulation by volatile fatty acids (VFA) during absorption. The degree of stimulation, hence satiation, appears to depend on the relative mix of VFA (butyrate > propionate > acetate) (Crichlow and Leek 1986), and stimulation is greatest at low pH when absorption is fastest. In other words, rapid production of VFA and low pH (rapid absorption of VFA across the rumen epithelium) are associated with greatest stimulation of epithelial receptors and a reduction in intake. Epithelial osmoreceptors are yet to be identified and characterised but there is evidence that feed intake is depressed when rumen osmolarity exceeds 40 mOsm/kg (Bergen 1972). Further support for the role of osmolarity is provided by the observation that local anaesthesia blocks osmolarity-induced hypophagia (Bergen 1972), suggesting the presence of neural receptors for osmolarity.

Post-absorptive effects of nutrients and metabolites on VFI

There is strong evidence that propionate in portal blood draining the ruminal viscera reduces feed intake in cattle (Anil and Forbes 1980; Elliot *et al.* 1985) and this appears to be a specific effect of propionate independent of osmolarity (Choi and Allen 1999). The effect of propionate on intake depression was greater than that of acetate. It is possible that the effect of propionate is via insulin production, since propionate increases insulin production (Manns *et al.* 1967) and insulin decreases VFI in sheep (Foster *et al.* 1991). However, depressed intake has been observed for propionate without changes in insulin (Farningham and Whyte 1993). The propionate-induced intake depression was also eliminated by hepatic denervation, suggesting a neural rather than hormonal axis (Anil and Forbes 1980).

A recent hypothesis has been developed to explain the impact of absorbed metabolites on the control of VFI in ruminants. Known as the hepatic oxidation theory, it suggests that receptors in the liver which are responsive to oxidisable fuels transmit information to the central nervous system via vagal afferents (Allen *et al*. 2009). The size and frequency of meals are proposed to be regulated by temporal changes in the absorption of nutrients, which are then oxidised in the liver. Afferent fibres of the vagus nerve are thought to carry signals to the brain to indicate the state of oxidation of fuels and the production of hepatic ATP (see Allen *et al*. 2009 for a review). Propionate is thought to be the primary satiety signal presumably because it is extensively converted to glucose or oxidised. Certainly, propionate infused into the portal vein has strong hypophagic effects relative to acetate (Quigley and Heitmann 1995), which is largely exported from the liver unchanged. Hepatic vagotomy blocks nutrient-induced satiety (Langhans *et al*. 1985), lending support to this theory. Of the metabolites available to the ruminant liver, only propionate, long-chain fatty acids, amino acids, lactate and glycerol are oxidised significantly in the liver. Acetate and glucose, in contrast, are poorly taken up by the ruminant liver (Stangassinger and Giesecke 1986; Reynolds 1995) and, consistent with the hepatic oxidation theory, therefore do not contribute to metabolite-induced satiety. Clearly then, rapid fermentation of substrates in the rumen, resulting in rapid VFA production, absorption and transport to the liver, is likely to reduce VFI compared to diets which are more slowly fermented or which pass to the intestines. This has been demonstrated in lactating cows fed starches differing in ruminal fermentability (Oba and Allen 2003).

Large effects of propionate relative to acetate in the afferent blood supply to the liver on VFI has important implications for finishing beef cattle on high-energy rations. Propionate is utilised more efficiently than acetate for maintenance and production, and increased propionate levels are a means of reducing methane production from ruminants (Van Nevel *et al*. 1974). Grain feeding and using ionophore growth promotants such as lasalocid and monensin increase the proportion of propionate in the VFA mix, which would be expected to reduce the potential total DMI of cattle, reducing some of the benefits of such rations and additives.

Higher central nervous system factors involved in VFI in cattle on energy-dense rations

The VFI of beef cattle on high-energy forage or concentrate diets is therefore governed by intrinsic characteristics of the feed, the metabolic signals of post-absorptive nutrients, and clinical or subclinical pathologies associated with unbalanced rumen functioning. However, ruminants also receive higher-level input from the central nervous system to modify feeding behaviour and intake (Villalba and Provenza 2009). These inputs reflect social facilitation, neophobia, neophilia, memory and experience (Albright 1993). Social facilitation is the phenomenon whereby the behaviour of the group or individuals within a group influences the feeding behaviour of other animals within the group. The clearest example is seen at the beginning and end of feeding sessions where one cow eating stimulates another to do so, even though she may not be 'hungry' (Albright 1993). Cows eating in groups eat more than when they are kept separately, so group feeding has a sound psychological basis (Scott 1962). Given that there is a wide genetic variance in individual feed intake it would be interesting to explore the potential for using high-intake animals to stimulate the total feed intake of a herd on the basis of this behavioural trait.

The relative roles of neophobia and neophilia are disputed in the literature. Neophobia is a well-known characteristic of ruminants and herbivores in general (Villalba and Provenza 2009), and is considered a means of avoiding overconsumption of toxic plant secondary metabolites not previously encountered (Provenza *et al*. 1995). Some studies indicate that ruminants prefer the familiar to the novel in terms of feed on offer and the environment in which the feeding takes place (Villalba *et al*. 2012). The extent to which this caution, directed towards novelty, is a fear response has been questioned (Herskin *et al*. 2003). These authors demonstrated that heart rate (as an indicator of fear or stress) was lower when cattle were presented with a novel foodstuff than when they were offered their usual food. The normal 'excitement' induced by familiar feeds was curtailed by novel feeds.

However, frequent exposure to the same diet may induce satiety through sensory-specific mechanisms which cause the animal to lose motivation for the familiar food, while diverse diets appear to restore motivation and food acceptability and intake (Rolls *et al*. 1981). Boland *et al*. (2011), for example, showed that cattle with previous experience of lucerne (*Medicago sativa*) spent less time grazing lucerne than those with no prior experience of lucerne. Similarly, Ganskopp and Cruz (1999) and Baumont *et al*. (2000) reported that ruminants readily consume novel foods. In natural systems, ruminants are exposed to a wide variety of feeds with widely varying concentrations of nutrients and plant secondary metabolites. The final diet is generally higher in nutrients and lower in secondary metabolites than the average of the feed on offer. The advantage of a diversity of feed sources is that the consumption of small quantities of secondary metabolites might confer pharmacological benefits which outweigh the potential for poisoning (Villalba and Provenza 2009). As animals learn the benefits of diverse feedstuffs, observational 'training' of offspring would pass on the acquired 'knowledge'. In summary, animals are balancing the advantages and disadvantages of consuming diverse foods, which may explain the apparent paradox between neophilia and neophobia in grazing animals. From a practical viewpoint, the intake of food by cattle on finishing diets may be stimulated by provision of more diverse foodstuffs, but care should be taken to ensure the cattle have been previously exposed to the feedstuff at an early age (Villalba *et al.* 2012).

Figure 16.4: Beef cattle grazing typical spring pastures in southern Australia (Mediterranean climate). Pastures meet the requirements to achieve maximal rates of liveweight gain only at limited times throughout the year. Photo: P.I. Hynd.

NUTRITIVE VALUE OF PASTURE PLANTS IN AUSTRALIA

Ideally pasture plants should be of high quality: there should be high DM digestibility, high CP content, a proportion of the plant protein should escape ruminal degradation, the mineral content should meet the animal's requirement in balance with other mineral elements (e.g. Ca:P, Mg:K), the NDF content should be optimal for rumen function (Fig. 16.3) and levels of potentially harmful compounds should be low. The quantity of pasture herbage should not limit intake and this typically occurs when total green DM exceeds ~2000 kg/ha. Only seldom are all these factors met by typical pasture systems. Improved pastures in temperate and Mediterranean regions of Australia are limited in providing sufficient quantity or quality of pasture herbage for rapid growth and finishing of beef cattle throughout the entire year (Figs 16.4, 16.5). In Mediterranean climates, pasture growth is restricted in late spring, summer and early autumn by limited rainfall and soil moisture. Following opening rains in autumn the pasture quality is high but the quantity is limited by cold temperatures, and in some environments by waterlogging. In spring, pasture growth rates and quality are high, allowing cattle to maximise intake of ME (Fig. 16.5). The quantity of pasture available is usually the first-limiting factor dictating the growth rate of cattle in many environments.

In cold temperate regions (e.g. the southern and northern tablelands of NSW), the growth of pastures is limited by temperature in autumn and winter. Depending on pasture types, and particularly for those containing legumes, growth rates of cattle can approach maxima from October through to April.

Given the relatively low cost of pastures (Table 16.5) compared to other nutrient-dense feeds such as grains, the efficient utilisation of the pasture base can be the most cost-effective system of beef production. Pasture budgeting and the appropriate use of grazing strategies based on pasture growth rates (Chapter 15) can significantly increase the utilisation of pasture from the current

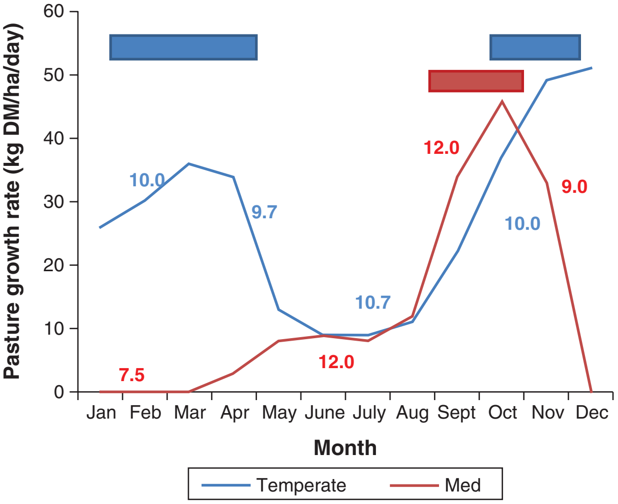


Figure 16.5: Typical seasonal growth rates (kg DM/ha/day) of temperate and Mediterranean pastures in Australia. The figures represent typical ME values (MJ/kg DM) for temperate (blue) and Mediterranean (red) pastures throughout the year. The boxes represent periods in which high growth rates (>1.0 kg/day) of cattle can be supported by the quantity and quality of pasture (MLA 2004). The energy data are derived from forage species estimates from temperate climates (Fulkerson *et al.* 2007) and Mediterranean climates (Walsh and Birrell 1987).

industry estimates of 30–40% to 50% of pasture grown. Choice of pasture species and cultivars suited to the environment and improving soil fertility can further improve the pasture-growing season and the quality of the feedbase.

Legumes are consumed at a significantly higher rate than grasses when compared at the same organic matter digestibility (Clark and Ulyatt 1985). This appears to be a consequence of increased chewing efficiency, and reduced ruminal retention time of the leguminous organic matter. The total quantity of nitrogen reaching the small intestines, and absorbed mineral elements, is higher for legumes than grasses. For these reasons the inclusion of legumes in swards significantly improves the growth rate of grazing cattle.

SUPPLEMENTARY FEEDING OF FINISHING BEEF CATTLE ON PASTURES AND FEEDLOTS IN AUSTRALIA

Supplementary feeding of cattle grazing poor- to medium-quality pastures is usually aimed at correcting nutrient deficiencies, improving animal performance by increasing total energy intake, or taking grazing pressure off pastures at critical times in plant growth. For growing and finishing cattle grazing high-quality pastures, ideally no supplement is required, but if deficiencies exist ideal supplements maximise DMI, maximise the digestibility of consumed forage, provide additional energy without reducing forage intake, increase the metabolisable protein supply (microbial plus UDP), maximise the efficiency of utilisation of absorbed nutrients, reduce digestive and metabolic upsets, or eliminate deficiencies of macro- and microminerals. In contrast to the situation with feedlot cattle fed standard rations, in forage-based finishing systems it is difficult to know precisely what the animals are consuming. Selective grazing and variable composition of the ingested nutrients make it difficult to identify the nutrients that are limiting the intake and the efficiency of utilisation of energy. Typical supplements and rumen-modifiers available for producers wishing to grow and finish cattle (Table 16.6).

Substitution effects of supplements

Ideally, feeding additional energy supplements to cattle at pasture would increase the total energy intake by at least the amount of extra energy consumed as supplement. This rarely occurs, because the intake of forage is depressed by the concentrate (Minson 1990). The substitution coefficient (ranging from 0, where there is no substitution effect and the total intake is increased by the same amount as the amount of supplement, to 1.0, where the intake of forage is depressed by the same amount as the supplement), varies widely depending on the characteristics of the forage, the type of supplement and the amount of supplement (Minson 1990). Substitution coefficients typically range from 0.3 to 0.6, indicating that there is usually a depression in forage intake equivalent to 30–60% of the supplement intake (Milne *et al.* 1981).

Rumen modifiers to improve rumen function in finishing cattle

Rumen modifiers (antibiotics, ionophores, methane inhibitors, defaunating agents) are used to achieve one or more of the following outcomes: amelioration of digestive or metabolic disturbances associated with the feeding of highly soluble carbohydrates and proteins (acidosis and bloat), modification of the rumen microflora and their metabolic pathways to increase the proportion of propionate in the VFA mix, reduction of methane output, increase in feed digestibility, increase in rumen pH, improvement in protein availability and more consistent feed consumption (Patra and Saxena 2009; Bretschneider *et al.* 2008; Calsamiglia *et al.* 2007). Ionophore modifiers are antibiotic growth promotants which influence rumen function by selectively modifying the rumen microflora. The ionophore rumen modifiers used in cattle feeding are monensin, lasalocid, narasin and salinomycin. They act predominantly by inhibiting the growth of lactate-producing bacteria such as *Lactobacillus* spp., *Butyrivibiro* spp., *Streptococcus bovis* and *Lachnospira* spp. Importantly, these modifications to rumen function reduce D- and L-lactate concentrations, increase pH, reduce the incidence of acidosis, generate more consistent eating patterns, reduce methane output and increase the proportion of propionate in the VFA mixture. The latter is considered a primary mechanism whereby growth promotion is achieved. Enhanced propionate production increases growth efficiency as a result of reduced methane production, increased post-absorptive glucose production, and sparing of glucogenic amino acids from glucose production. In commercial feedlots, ionophores improve feed conversion ratio by reducing DMI while maintaining average daily gain (Morris *et al.* 1990; DiConstanzo *et al.* 1996). Less is known of the responses to antibiotic growth promotants of cattle grazing forages. Chalupa (1979) showed an increase of 17% in the average daily gain of cattle at pasture, to monensin, but there appears to be an interaction between forage quality and response to

Table 16.6: Typical supplements and rumen-modifiers available for growing and finishing cattle

Supplement	Typical examples	Modes of action and comments
Energy supplements	• Cereal grains (barley, wheat, oats, triticale) • Molasses • Grain legumes (peas, beans, lupins)	• Increased total energy intake • Substitution effect on pastures • Reduced fibre digestion • Potential acidosis • Legume grains operate as high-energy and high-protein supplements
Fibre supplements	• Oat husks • Rice husks • Wheat husks • Cotton hull waste • Grape marc	• Increase NDF to achieve optimal level in ration to maximise intake and stabilise rumen function • Increased feed intake if NDF too low • Reduced acidosis
RDP supplements	• Urea	• Unlikely response in growing/finishing rations as RDP already adequate
Undegraded dietary protein supplements	• Soybean meal • Cottonseed meal • Canola meal • Lupins • Field peas • Field beans	• Increased metabolisable protein supply • Possibly increased feed intake (total energy increase)
Rumen modifiers (ionophores)	• Monensin • Lasalocid • Narasin • Salinomycin • Tetronasin • Lysocellin • Laidlomycin	• Decreased acidosis • More uniform feed intake • Increased energy efficiency (increased propionate, reduced methane) • Feed intake reduced, daily gain maintained (increased feed conversion efficiency) • Reduced nitrogen excretion • Reduced phosphorus excretion
Rumen modifiers (other antibiotics)	• Virginiamycin • Tylosin • Bambermycin	• Increased daily gain and feed efficiency • Decreased lactic acidosis • Decreased laminitis • Improved mineral absorption
Rumen modifiers (pH buffers)	• $NaHCO_3$ • MgO • Na bentonite • $CaCO_3$	• Reduced acidosis • Increased feed intake
Rumen modifiers (miscellaneous)	• Garlic oil • Cinnamaldehyde • Eugenol • Capsaicin • Anise oi • Tannins • Saponins	• Increased propionate:acetate ratio • Reduced proteolysis/deamination • Reduced methane production

Source: Adapted from Patra and Saxena (2009); Calsamiglia *et al.* (2007); Russell and Strobel (1989).

antibiotic growth promotants (Bretschneider *et al.* 2008). These authors surveyed the literature and found that as forage quality increased, the response in daily gain to monensin decreased, but to lasolacid it increased.

A wide range of phytochemicals and other bioactives with potential as beneficial rumen modifiers have been tested, including saponins, tannins, garlic oil, anise, capsicum extract, cinnamaldehyde, eugenol and yeasts. The search for non-antibiotic compounds which reduce the risk of ruminal acidosis and bloat has intensified since the European Union banned the use of antibiotics in animal feeds in 2006. The challenge is to identify compounds that are not only effective but which can also be practically supplied to the daily ration of feedlot and grazing cattle.

Several bioactive agents have shown promise in feeding trials. Live yeast supplementation of dairy cows on high-starch rations, for example, has produced promising results. Marden *et al*. (2008) showed that live yeast reduced the pH decline and rumen lactate levels, and Ferraretto *et al*. (2012) showed that live yeast supplementation increased NDF digestibility and milk fat content. Saponins have potential as growth promotants through their inhibitory effects on ruminal ciliates and inhibition of methane-generating archea (Patra and Saxena 2009). Tannins (high molecular weight polyphenolics) have potential as rumen modifiers by reducing ruminal protein degradation, inhibiting ruminal protozoa, reducing the incidence of bloat and reducing methane production (Patra and Saxena 2009). Further studies of a potential role for rumen-active bioagents are urgently required to replace antibiotic growth promotants for grain-fed and forage-fed beef cattle.

NUTRITIONAL DISEASES OF CATTLE GRAZING HIGH-ENERGY PASTURES AND GRAIN CONCENTRATES

Bloat

The requirement for energy-dense rations (10–14 MJ/kg DM) for finishing beef cattle increases the proportion of the diet comprising cell contents (starches and sugars) relative to cell wall constituents (cellulose, hemicelluloses, lignin). Rapid fermentation of highly soluble cell contents leads to rapid accumulation of fermentation acids and bacterial mucopolysaccharides, which in turn leads to the formation of frothy or foamy rumen contents. Large volumes of gas accumulate in the frothy bubbles which cannot be eructated due to the stable nature of the foam or to failure of the vagally mediated opening of the oesophageal cardia. Two forms of bloat are considered to occur: 1) free gas bloat, in which gas accumulates in the dorsal sac of the rumen as a consequence of mechanical obstruction of the cardia or oesophagus, damage to the vagus nerve, chronic pneumonia or impaired rumen motility due to acidosis or hypocalcaemia, and 2) frothy bloat. The latter can occur at pasture or in feedlots. In pasture or legume bloat the froth is formed from plant components (Mangan 1988; Majak *et al*. 1995) and, while the foam is of a complex nature, it is largely proteinaceous (Clarke and Reid 1974). Soluble proteins in general, and Fraction 1 leaf protein in particular, have been implicated as causative agents in the formation of stable foam (Majak *et al*. 1995) but previous associations of plant saponins and bloat incidence have not been upheld (Majak *et al*. 1995). Grasses are less likely to produce pasture bloat than legumes, and among legumes there are large differences in bloat-susceptibility. Alfalfa (*Medicago sativa*) and the clovers (*Trifolium* spp.) are commonly cited as bloat-inducing while there are few reports of bloat induced by tropical legumes. Sainfoin (*Onobrychis viciifolia*), birdsfoot trefoil (*Lotus corniculatis*), lespedeza, crownvetch, and cicer milkvetch (*Astragalus cicer*) are considered bloat-safe. 'Bloat-safe' forages appear to be characterised by thicker, stronger cell walls which reduce the rate of DM digestion. Polyphenolic compounds (tannins) in the plant also reduce bloat by binding to plant-soluble proteins and inhibiting microbial activity.

Feedlot bloat (frothy) is associated with the feeding of high-grain diets, particularly those that have been finely ground. Rapid fermentation of the starch decreases ruminal pH, resulting in the rupture of bacterial cells and the release of extracellular mucopolysaccharides, which in turn increases the viscosity and frothiness of the rumen digesta.

Prevention rather than treatment of bloat should be the aim of beef producers. The amount of roughage, use of low-risk grains (oats, lupins), choice of grain processing, use of feed additives such as ionophores, and ensuring animals are adapted to the ration, can be optimised to reduce the incidence of feedlot bloat. The rate and extent of fermentation of wheat grain is greater than that of barley, corn and sorghum (McAllister *et al*. 1990) and the resulting frequency of acidosis is higher in wheat-fed cattle than those fed other cereal grains (Elam 1976). Whether this translates to feedlot bloat incidence is not clear. Grain treatments which increase the surface area available for microbes, increase the rate of production of acids and mucopolysaccharides which reduce the pH and increase the viscosity of the ruminal fluid.

For forage bloat, increasing the proportion of grass species in the pasture mix, use of bloat-safe forages (sainfoin, birdsfoot trefoil, cicer milkvetch and crownvetch) and strategic grazing management (providing coarse hay before legume pasture, temporary removal from legume pastures, introducing cattle to pastures in the afternoon) are useful strategies (Majak *et al.* 2012). Poloxalene, oils and detergents act as anti-foaming agents in forage bloat.

Nitrate/nitrite poisoning

Nitrate is the major inorganic soil nitrogen source for plant growth but, when the supply of nitrate exceeds its conversion to organic nitrogen compounds, the excess nitrate accumulates in the plant. Factors favouring nitrate accumulation include plant species (Wright and Davison 1964; Table 16.7), stage of plant maturity (Wright and Davison 1964), potassium application, frost, sudden temperature changes, shading and insect damage (O'Hara and Fraser 1975). Plants that are particularly prone to nitrate accumulation are members of the Brassica family (e.g. turnips, rape, choumoellier), various *Lolium* species, green oats (*Avena* spp.), *Sorghum* species, variegated thistle (*Silybum marianum*) and winged thistle (*Carduus tenuiforus*) (Table 16.7). Typically, plants growing rapidly after a growth check, in high-nitrogen soils, are particularly prone to nitrate accumulation. Nitrate is rapidly converted to nitrite in the reductive environment of the reticulorumen. The nitrite is absorbed across the ruminal epithelium, entering the bloodstream where it oxidises ferrous ions to ferric ions. Haemoglobin is converted to methaemoglobin which has very poor affinity for oxygen, resulting in hypoxia in the animal. Sudden death ensues;

Table 16.7: Plant secondary metabolites present in common pasture plant species in Australia

Metabolite type	Plant species	Principal effects and modes of action
Condensed tannins	*Acacia* spp. *Lotus corniculatis* *Hedysarum coronarium* *Onobrychus viciifolia*	• Reduced microbial activity depending on concentration • Reduced protein digestion • Reduced rumen degradation of protein hence increased UDP supply but often reduced intestinal absorption
Oxalates	*Acacia* spp. *Oxalis pes-caprae* *Cenchrus ciliaris* *Pennisetum clandestinum*	• Reduced plasma calcium • Staggering • Recumbency • Urolithiasis • Pulmonary oedema due to capillary damage by absorbed oxalates
Cyanogenic glucosides	*Trifolium repens* *Trifolium subteraneum* *Sorghum* spp. *Cynadon* spp.	• Goitre • Cyanide poisoning
Goitrogenic glucosides	*Brassica* spp.	• Reduced thyroid function • Goitre
Phyto-oestrogens (Isoflavones, coumestans, fungal oestrogens)	*Trifolium subterranean* *Trifolium pratense* *Medicago sativa*	• Infertility
Tryptamine alkaloids	*Phalaris aquatica*	• Neurological staggers
Pyrollizidine alkaloids	*Heliotropium europeum* *Echium plantaginium*	• Hepatoxic • Copper poisoning • Depression • Diarrhoea
Indole alkaloids	*Festuca, Phalaris* and *Lolium endophytes*	• Vasoconstriction and associated hyperthermia • Staggering
Quinolizidine alkaloids	*Lupinus angustifolius*	• Respiratory paralysis • Central nervous system damage
Nitrates	*Avena sativa* *Lolium* spp. *Medicago sativa* *Brassica* spp.	• Hypoxia • Dyspnoea • Ataxia • Death • Cyanosis • Chocolate coloured blood
Mycotoxins:Sporidesmin Lolitrem A, B, C, D Ergovaline	*Lolium* spp. *Festuca* spp. *Paspalum dilatatum*	• Hepatotoxic • Photosensitisation • Jaundice • Vasoconstriction

Source: Adapted from Cheeke (1995); Waghorn *et al.* (2002).

there is no evidence of struggling. Live animals exhibit ataxia, dyspnoea, cyanosis and, diagnostically, have chocolate-coloured blood which rapidly re-oxidises on exposure to air (Vermunt and Visser 1987). Rate of intake of high-risk forage is a major predisposing factor to nitrate/nitrite poisoning as the rumen microbes have insufficient time to convert the nitrite to ammonia. Prevention of nitrate poisoning should be the aim of beef producers. Prevention includes not introducing hungry cattle to potentially toxic pastures, providing low-nitrate feeds such as hay, removing high-risk species such as capeweed, and not grazing high-risk pastures for seven days after high rainfall, frost or wilting. Intravenous methylene blue converts methaemoglobin back to oxygen-carrying haemoglobin as a treatment for affected animals (however, methylene blue is no longer approved by the Australian Pesticides and Veterinary Medicines Authority for treatment of food-producing animals).

Ruminal lactic acidosis and subacute ruminal acidosis

High-energy pasture or grain diets (10–14 MJ/kg DM) for finishing cattle are associated with the ingestion of large amounts of highly fermentable soluble carbohydrates which can produce a continuum of acidosis-related diseases and dysfunctions, including acute lactic acidosis, sudden death, polioencephalomalacia, hypocalcaemia, ruminitis, lameness (laminitis), hepatic abscesses, reduced feed intake, lung haemorrhages, bloat, clostridial infections, diarrhoea, ruminal stasis, dehydration and poor immune function (RAGFAR 2007). External signs of acidosis include weakness, incoordination, anorexia and faeces that are grey, soft and foamy (Glock and DeGroot 1998). The subclinical form of the disease (subacute ruminal acidosis) is economically more important than the acute form and has been estimated to affect 10% of dairy cows in NSW and Victoria (Bramley *et al.* 2008). The subclinical form of acidosis is associated with reduced milk fat in dairy cows, reduced feed intake and poor digestion of fibre, left displacement of the abomasum, liver abscessation, scouring and laminitis (RAGFAR 2007). The precise definitions of acute and subclinical acidosis are debated, but typical cut-off points are ruminal pH of 5.6 (Owens *et al.* 1998) for subacute and 5.0 for acute acidosis (Garrett *et al.* 1999). Considerable research has been conducted on grain-induced acidosis in which rapid fermentation of starch and failure to degrade the resulting lactic acid reduces the pH, but less is known of acidosis induced by low-fibre lush pastures. In contrast to acute acidosis, subacute acidosis is associated with an accumulation of VFA rather than lactate (Nagaraja and Titgemeyer 2007). It is unclear why the VFA accumulate in subacute acidosis, as the absorption of the acids should increase as their concentration in the rumen increases. Changes in osmolarity of the rumen fluid may play a role in reducing VFA absorption (Huber 1976). Lactic acidosis in feedlot cattle can be prevented by ensuring a transitional feeding regime which allows the microbes to adapt to the concentrate ration. Addition of virginiamycin, ionophores susch as monensin, and buffers can be effective. Roughage components should be a minimum of 5 cm in length to allow effective stimulation of the ruminal epithelium, and increased salivation.

Polioencephalomalacia

Polioencephalomalacia (PEM) or cerebrocortical necrosis (CCN) is a neurologic disorder of ruminants which can be initiated by a variety of metabolic disorders related to diet. The condition occurs in feedlot cattle but it has also been recorded in grazing cattle. Symptoms of PEM include blindness, muscle tremors, ataxia and seizures (Gould 1998). PEM is often referred to as a specific neurological disease caused by a deficiency of thiamine (vitamin B1), but more recently the brain lesion and symptoms are considered to be caused by a variety of pathophysiological states induced by high sulphur intake (Gooneratne *et al.* 1989), acute lead poisoning (Little and Sorenson 1969) and water deprivation/sodium ion toxicoses (Padovan 1980). Sulphur-associated PEM can be induced by a high intake of sulphates in the water supply (Harris 1987) or by high levels of sulphur compounds in the diet (Raisbeck 1982). A specific, sulphur-induced PEM is associated with the feeding of molasses (containing high levels of sulphur) in feedlot rations (Mella *et al.* 1976). The role of thiamine in the aetiology of PEM is supported by decreased thiamine concentrations in body tissues, decreased activity of the thiamine-enzyme, transketolase, in blood (Edwin and Jackman 1973), increased levels of thiaminases in the gastrointestinal tract (Edwin *et al.* 1968) and positive responses to parenteral thiamine supplementation (Davies 1965). The association between the development of PEM, acidosis on feedlot rations, the microbial production of thiaminases and the presence of hydrogen sulphide in the rumen gas space, reflects a complex aetiology which is only partially understood.

Urolithiasis

Obstructive urolithiasis (waterbelly) is a condition mainly of male cattle, in which the urethra is blocked by uroliths or stones formed by the precipitation of calcium salts (carbonates or oxalates). The condition occurs on typical feedlot diets (high grain) in which the calcium:phosphorus ratio is less than 1.5–2:1. Struvite uroliths are most common in grain-fed cattle due to a poor calcium:phosphorus ratio, while diets high in calcium (some clovers) result in calcium carbonate uroliths. Plants containing high levels of oxalates (e.g. *Oxalis pes-caprae*) can produce uroliths of calcium oxalate but tend to be unpalatable. The uroliths usually lodge in the distal aspect of the sigmoid flexure, blocking urination and causing extreme pain, inappetence, bloat, weight-shifting, bloody urine, rectal prolapse and uraemia (Waltner-Toews and Meadows 1980).

Anti-nutritive factors in pasture plants in Australia

Toxic compounds in pasture plants are either produced by the plant as a 'secondary' metabolite which is not required for the main plant processes of growth and reproduction, or from an interaction between the plant and endophytic fungi. The former are thought to be produced to protect the plant from herbivory by grazing animals (Iason 2005) and the latter to protect from insect damage (Easton 1999). A wide range of toxic substances is associated with temperate pastures including alkaloids, glycosides, phylloerythrin, S-methylcysteine sulphoxide, oxalates, condensed tannins, oestrogens, nitrates and anti-vitamin compounds (Cheeke 1995) in addition to the mycotoxins (Table 16.7). Perennial ryegrass toxicity is a neural disorder of sheep, cattle, horses and deer grazing perennial ryegrass-dominant pastures in Australia and New Zealand. The neurotoxic components are the lolitrems A, B, C and D produced by fungal endophytes from *Acremonium* spp.

While there are some reported positive effects of the consumption of limited quantities of certain plant secondary metabolites on gastrointestinal parasitism and protein digestion in ruminants (Athanasiadou and Kyriazakis 2004), consumption of plant secondary metabolites appears to be an accidental rather than a deliberate choice. Any positive effects of these compounds must be balanced against their negative effects. In many cases the metabolites reduce the intake of the particular forage and total diet (Iason 2005). While some grasses contain defence metabolites, they rely more on growth habit to avoid herbivory than legumes and woody forages, which contain a variety of secondary compounds including alkaloids, glycosides, polyphenolics and toxic amino acids (Cheeke 1995). Grasses often appear to have adopted defence strategies in concert with fungi which produce toxins, affording protection against insect attack (Waghorn *et al*. 2002). Table 16.7 lists the major plant secondary metabolites found in pasture plants and shrubs in Australia.

Conclusion

Achieving high rates of gain in finishing beef cattle requires rations containing a high density of ME (>10 MJ/kg DM), high CP levels (>16%), a proportion of which escapes ruminal degradation, and a balance of macro- and trace minerals. Maximal rates of VFI are achieved when the digestibility (energy content) of the feed is maximised, provided rumen function is not compromised by rapid acid production. This is best achieved by optimising the NDF content of the ration to achieve a balance between energy demand-driven intake and gut fill-limited intake. Supplements can be used to elevate the energy, protein or mineral levels of the ration and are most economically efficient when they eliminate a deficiency in the base ration, for example by providing a limiting macro- or trace element. Rumen-modifiers can be used to improve digestive efficiency, alter the balance of end products and possibly to reduce methane production by the ruminal organisms. Beef cattle on high-energy pastures and feedlot rations are prone to several debilitating conditions including nitrate poisoning, oxalate poisoning, polioencephelomalacia, urolithiasis, hypocalcaemia, hypomagnesaemia, bloat, acute acidosis and subacute ruminal acidosis. Pasture plants can contain anti-nutritive secondary compounds which can reduce the intake, digestion and utilisation of nutrients. Efficient beef cattle production systems in the future will maximise the production and utilisation of high-quality pastures; match the high genetic demands of rapidly growing genotypes with energy, microbial end products, and metabolisable amino acids that match the essential amino demands of rapid growth; minimise the losses of energy in compounds such as methane; and minimise diseases.

REFERENCES

AFRC (1992) Nutrient requirements of ruminant animals: protein. Technical committee on responses to nutrients. Rep. No 9. *Nutrition Abstracts and Reviews* **62**, 787–835.

Agricultural Research Council (1980) *The Nutrient Requirements of Domestic Livestock*. Commonwealth Agricultural Bureau.

Albright JL (1993) Feeding behaviour of dairy cattle. *Journal of Dairy Science* **76**, 485–498. doi:10.3168/jds.S0022-0302(93)77369-5.

Allen MS (1996) Physical constraints on voluntary intake of forages by ruminants. *Journal of Animal Science* **74**, 3063–3075.

Allen MS (2000) Effects of short-term regulation of feed intake by lactating dairy cattle. *Journal of Dairy Science* **83**, 1598–1624. doi:10.3168/jds.S0022-0302(00)75030-2.

Allen MS, Bradford BJ, Oba M (2009) The hepatic oxidation theory of the control of feed intake and its application in ruminants. *Journal of Animal Science* **87**, 3317–3334. doi:10.2527/jas.2009-1779.

Anand BK, Brobeck JR (1951) Localisation of a feeding center in the hypothalamus of the rat. *Proceedings of the Society for Experimental Biology and Medicine* **77**, 323–325. doi:10.3181/00379727-77-18766.

Anil MH, Forbes JM (1980) Feeding in sheep during intraportal infusions of short-chain fatty acids and the effect of liver denervation. *Journal of Physiology* **298**, 407–414.

Arelovich HM, Abney CS, Vizcarra JA, Galyean ML (2008) Effects of dietary neutral detergent fiber on intakes of dry matter and net energy by dairy and beef cattle: analysis of published data. *Professional Scientists* **24**, 375–383.

Athanasiadou S, Kyriazakis I (2004) Plant secondary metabolites: antiparasitic effects and their role in ruminant production systems. *Proceedings of the Nutrition Society* **63**, 631–639. doi:10.1079/PNS2004396.

Bach A, Calsamiglia S, Stern MD (2005) Nitrogen metabolism in the rumen. *Journal of Dairy Science* **88**(E), suppl9.

Baile CA, Forbes JM (1974) Control of feed intake and regulation of energy balance in ruminants. *Physiological Reviews* **54**, 160–214.

Baumont R, Prache S, Meuret M, Morand-Fehr P (2000) How forage characteristics influence behaviour and intake in small ruminants: a review. *Livestock Production Science* **64**, 15–28. doi:10.1016/S0301-6226(00)00172-X.

Bergen WG (1972) Rumen osmolality as a factor in feed intake control of sheep. *Journal of Animal Science* **34**, 1054–1060.

Blaxter KL, Wainman FW, Wilson RS (1961) The regulation of food intake by sheep. *Animal Production* **3**, 51–61. doi:10.1017/S0003356100033766.

Boguhn J, Kluth H, Steinhafel O, Peterhansel M, Rodehutscord M (2003) Nutrient digestion and prediction of metabolisable energy in total mixed rations for ruminants. *Archives of Animal Nutrition* **57**, 253–266. doi:10.1080/00039420310001594405.

Boland HT, Scaglia G, Notter DR, Rook AJ, Swecker WS Jr, Abaye AO (2011) Grazing behaviour and diet preference of beef steers grazing adjacent monocultures of tall fescue and alfalfa. II. The role of novelty. *Crop Science* **51**, 1815–1823. doi:10.2135/cropsci2010.06.0375.

Bramley E, Lean IJ, Fulkerson WJ, Stevenson MA, Rabiee AR, Costa ND (2008) The definition of acidosis in dairy herds predominantly fed on pasture and concentrates. *Journal of Dairy Science* **91**, 308–321. doi:10.3168/jds.2006-601.

Bretschneider G, Elizalde JC, Perez FA (2008) The effect of feeding antibiotic growth promoters on the performance of beef cattle consuming forage-based diets: a review. *Livestock Science* **114**, 135–149. doi:10.1016/j.livsci.2007.12.017.

Calsamiglia S, Busquet M, Cardozo PW, Castillejos L, Ferret A (2007) Invited review: essential oils as modifiers of rumen microbial fermentation. *Journal of Dairy Science* **90**, 2580–2595. doi:10.3168/jds.2006-644.

Campling RC, Balch CC (1961) Factors affecting the voluntary fed intake of the cow. 1. Preliminary observations on the effect, on the voluntary intake of hay, of changes in the amount of the reticulo-ruminal contents. *British Journal of Nutrition* **15**, 523–530. doi:10.1079/BJN19610065.

Cheeke PR (1995) Endogenous toxins and mycotoxins in forage grasses and their effects on livestock. *Journal of Animal Science* **73**, 909–918.

Choi BR, Allen MS (1999) Intake regulation by volatile acids and physical fill *South African Journal of Animal Science* **29**, 40–41.

Clark DA, Ulyatt MJ (1985) Utilisation of forage legumes in ruminant livestock production in New Zealand. In *Forage Legumes for Energy-efficient Animal Production: Proceedings of an International Workshop,* Palmerston North, New Zealand, 30 April–4 May 1984. (Ed. R.F Barnes) p. 197. USDA-ARS, New Orleans.

Clarke RTJ, Reid CSW (1974) Foamy bloat of cattle: a review. *Journal of Dairy Science* **57**, 753–785. doi:10.3168/jds.S0022-0302(74)84964-7.

Clark JH, Klusmeyer TH, Cameron MR (1992) Microbial protein synthesis and flows of nitrogen fractions to the duodenum. *Journal of Dairy Science* **75**, 2304–2323. doi:10.3168/jds.S0022-0302(92)77992-2.

Conrad HR, Pratt AD, Hibbs JW (1964) Regulation of feed intake in dairy cows. 1. Change in importance of physical and physiological factors with increasing digestibility. *Journal of Dairy Science* **47**, 54. doi:10.3168/jds.S0022-0302(64)88581-7.

Crichlow EC, Leek BF (1986) Forestomach epithelial receptor activation by rumen fluids from sheep given intraruminal infusions of volatile fatty acids. *American Journal of Veterinary Science* **47**, 1015–1018.

Davies ET (1965) Cerebrocortical necrosis in calves. *Veterinary Record* **77**, 290.

Dinius DA, Baumgardt BR (1970) Regulation of food intake in ruminants. 6. Influence of caloric density of pelleted rations. *Journal of Dairy Science* **53**, 311–316. doi:10.3168/jds.S0022-0302(70)86202-6.

Easton HS (1999) Endophyte in New Zealand pastures: an overview. In *Ryegrass Endophyte:An Essential New Zealand Symbiosis*. (Eds DR Woodfield and C Mathew) pp. 1–10. Grasslands Research and Practice Series No. 7, New Zealand Grassland Association, Palmerston North.

Edwin EE, Jackman R (1973) Ruminal thiaminase and tissue thiamine in cerebrocortical necrosis. *Veterinary Record* **92**, 640. doi:10.1136/vr.92.24.640.

Edwin EE, Lewis G, Allcroft R (1968) Cerebrocortical necrosis: a possible role for thiaminase in its pathogenesis. *Veterinary Record* **83**, 176.

Elam CJ (1976) Acidosis in feedlot cattle: practical observations. *Journal of Animal Science* **43**, 898–901.

Ferraretto LF, Shaver RD, Bertics SJ (2012) Effects of dietary supplementation with live-cell yeast at two dosages on lactation performance, ruminal fermentation and total-tract digestibility in dairy cows. *Journal of Dairy Science* **95**, 4017–4028. doi:10.3168/jds.2011-5190.

Forbes JM (2007) *Voluntary Feed Intake and Diet Selection in Farm Animals.* 2nd edn. CAB International, Wallingford, UK.

Forbes JM, Barrio JP (1992) Abdominal chemo- and mechanosensitivity in ruminants and its role in in the control of food intake. *Experimental Physiology* **77**, 27–50.

Foster LA, Ames NK, Emery RS (1991) Food intake and serum insulin responses to intraventricular infusions of insulin and IGF-1. *Physiology and Behavior* **50**, 745–749. doi:10.1016/0031-9384(91)90012-D.

Fulkerson WJ, Neal JS, Clark CF, Horadagoda A, Kandra KS, Barchia I (2007) Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: grasses and legumes. *Livestock Science* **107**, 253–264. doi:10.1016/j.livsci.2006.09.029.

Galyean ML, Defoor PJ (2003) Effects of roughage source and level on intake by feedlot cattle. *Journal of Animal Science* **81**(E), Suppl.2 E8–E16.

Ganskopp D, Cruz R (1999) Selective differences between naive and experienced cattle foraging among eight grasses. *Applied Animal Behaviour* **62**, 293–303. doi:10.1016/S0168-1591(98)00233-0.

Garrett EF, Pereira MN, Nordlund KV, Armentano LE, Goodger WJ, Oetzel GR (1999) Diagnostic methods for the detection of subacute ruminal acidosis in dairy cows *Journal of Dairy Science* **82**, 1170–1178. doi:10.3168/jds.S0022-0302(99)75340-3.

Glock RD, DeGroot BD (1998) Sudden death of feedlot cattle. *Journal of Animal Science* **76**, 315–319.

Gooneratne SR, Olkowski AA, Klemmer RG (1989) Sulfur-induced polioencephelomalacia in sheep: some biochemical changes. *Canadian Journal of Veterinary Research* **53**, 462

Gould DH (1998) Polioencephalomalacia. *Journal of Animal Science* **76**, 309–314.

Grovum WL (1987) A new look at what is controlling food intake. In *Feed Intake by Beef Cattle: Symposium Proceedings.* (Ed. FN Owens). Oklahoma State University, Stilwater, OK.

Harding R, Leek BF (1972) Gastro-duodenal receptor responses to chemical and mechanical stimuli, investigated by a 'single fibre' technique. *Journal of Physiology* **222**, 139–140.

Harris WN (1987) Polioencephelomalacia in feedlot cattle drinking water high in sodium sulphate. *Canadian Veterinary Journal. La Revue Veterinaire Canadienne* **28**, 717.

Herskin MS, Munksgaard L, Kristensen A-M (2003) Testing responses to novelty in cattle: behavioural and physiological responses to novel food. *Animal Science* **76**, 327–340.

Huber TL (1976) Physiological effects of acidosis on feedlot cattle. *Journal of Animal Science* **43**, 902–909.

Iason G (2005) The role of plant secondary metabolites in mammalian herbivory: ecological perspectives. *Proceedings of the Nutrition Society* **64**, 123–131. doi:10.1079/PNS2004415.

Jung HG, Allen MS (1995) Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. *Journal of Animal Science* **73**, 2774–2790.

Langhans W, Egli G, Scharrer E (1985) Selective hepatic vagotomy eliminates the hypophagic effect of different metabolites. *Journal of the Autonomic Nervous System* **13**, 255–262. doi:10.1016/0165-1838(85)90014-1.

Leek BF (1986) Sensory receptors in the ruminant alimentary tract. In *Control of Digestion and Metabolism in Ruminants.* (Eds LP Milligan, LP Grovum and A Dobson) pp. 3–17. Prentice Hall, Englewood Cliffs.

Lippke H (1986) Regulation of voluntary intake of ryegrass and sorghum forages in cattle by indigestible neutral fiber. *Journal of Animal Science* **63**, 1459–1468.

Little PB, Sorenson DK (1969) Bovine polioencephalomalacia, infectious embolic meningoencephelitis and acute lead poisoning in feedlot cattle. *Journal of the American Veterinary Medical Association* **155**, 1892.

MacPherson A, Gray D, Mitchell GBB, Taylor CN (1987) Ostertagia infection and neutrophil function in cobalt-deficient and cobalt-supplemented cattle. *British Veterinary Journal* **143**, 348–353. doi:10.1016/0007-1935(87)90069-8.

MAFF (1975) *Energy Allowances and Feeding Systems for Ruminants.* Technical Bulletin 33. Ministry of Agriculture, Fisheries and Food.

Majak W, Hall JW, McCaughey WP (1995) Pasture management strategies for reducing the risk of legume bloat in cattle. *Journal of Animal Science* **73**, 1493–1498.

Mangan JL (1988) Nutritional effects of tannins in animal feeds. *Nutrition Research Reviews* **1**, 209–231. doi:10.1079/NRR19880015.

Manns JG, Boda JM, Willes RF (1967) Probable role of propionate and probably butyrate in control of insulin secretion in sheep. *American Journal of Physiology* **121**, 756–764.

Marden JP, Julien C, Monteils V, Auclair E, Moncoulon R, Bayourthe C (2008) How does live yeast differ from sodium bicarbonate to stabilise ruminal pH in high-yielding dairy cows? *Journal of Dairy Science* **91**, 3528–3535. doi:10.3168/jds.2007-0889.

McAllister TA, Rode LM, Major DJ, Cheng K-J, Buchanan-Smith JG (1990) Effect of ruminal microbial colonisation on cereal grain digestion. *Canadian Journal of Animal Science* **70**, 571–579. doi:10.4141/cjas90-069.

Mella CM, Perez-Oliva O, Loew FM (1976) Induction of bovine polioencephalomalacia with feeding system based on molasses and urea. *Canadian Journal of Comparative Medicine* **40**, 104.

Mertens DR (2009) Impact of NDF content and digestibility on dairy cow performance. *WCDS Advances in Dairy Technology* **21**, 191–201.

Milne JA, Maxwell TJ, Souter W (1981) Effect of supplementary feeding and herbage mass on the intake and performance of grazing ewes in early lactation. *Animal Production* **32**, 185–196. doi:10.1017/S0003356100024995.

Minson DJ (1990) *Forage in Ruminant Nutrition.* Academic Press, London.

MLA (2004) *More Beef from Pastures. Module 4: Pasture utilisation.* <http://www.mla.com.au/research-and-development/extension-and-training/more-beef-from-pastures>.

Nagaraja TG, Titgemeyer EC (2007) Ruminal acidosis in beef cattle: the current microbiological and nutritional outlook.

Journal of Dairy Science **90**(E), suppl. E17–E38. doi:10.3168/jds.2006-478.

NRC (1996) *Nutrient Requirements of Beef Cattle*. 7th edn. National Research Council.

O'Hara PJ, Fraser AJ (1975) Nitrate poisoning in cattle grazing crops. *New Zealand Veterinary Journal* **23**, 45.

Oba M, Allen MS (2003) Effects of corn grain conservation method on feeding behaviour and productivity of lactating dairy cows at two different starch concentrations. *Journal of Dairy Science* **86**, 174–183. doi:10.3168/jds.S0022-0302(03)73598-X.

Owens FN, Secrist WJ, Hill WJ, Gill DR (1998) Acidosis in cattle: a review. *Journal of Animal Science* **76**, 275–286.

Padovan D (1980) Polioencephalomalacia associated with water intoxication in cattle. *Cornell Veterinarian* **70**, 153.

Patra AK, Saxena J (2009) Dietary phytochemicals as rumen modifiers: a review of the effects on microbial populations. *Antonie van Leeuwenhoek* **96**, 363–375. doi:10.1007/s10482-009-9364-1.

Phillip LE, Buchanan-Smith JG, Grovum WL (1981) Food intake and ruminal osmalality in sheep: differentiation of the effect of osmalality from that of the products of maize silage fermentation. *Journal of Agricultural Science* **96**, 439–445. doi:10.1017/S002185960006620X.

Poppi DP, Norton BW, Minson DJ, Hendricksen RE (1980) The validity of the critical size theory for particles leaving the rumen. *Journal of Agricultural Science* **94**, 275. doi:10.1017/S0021859600028859.

Provenza FD, Lynch JJ, Cheney CD (1995) Effects of a flavour and food restriction on the response of sheep to novel foods. *Applied Animal Behaviour Science* **43**, 83–93. doi:10.1016/0168-1591(95)00552-4.

Quigley JD, Heitmann RN (1995) Effects of propionate infusion and dietary energy on dry matter intake in sheep. *Journal of Animal Science* **69**, 1178–1187.

RAGFAR (2007) *Ruminal Acidosis-aetiopathogenesis: Prevention and Treatment. A Review for Veterinarians and Nutritional Professionals*. Reference Advisory Group on Fermentative Acidosis of Ruminants. Australian Veterinary Association.

Raisbeck MF (1982) Is polioencephalomalacia associated with high-sulfate diets? *Journal of the American Veterinary Medical Association* **180**, 1303.

Reynolds CK (1995) Quantitative aspects of liver metabolism in ruminants. In *Ruminant Physiology: Digestion, Metabolism, Growth and Reproduction*. (Eds WV Englehardt, S Leonhard-Marek, G Breves and D Giesecke) pp. 351–372, Verlag, Stuttgart.

Roche JR, Blache D, Kay JK, Miller DR, Sheahan AJ, Miller DW (2008) Neuroendocrine and physiological regulation of intake with particular reference to domesticated ruminant animals. *Nutrition Research Reviews* **21**, 207–234. doi:10.1017/S0954422408138744.

Rolls BJ, Rowe EA, Rolls ET, Kingston B, Megson A, Gunary R (1981) Variety in a meal enhances food intake in man. *Physiology and Behavior* **26**, 215–221. doi:10.1016/0031-9384(81)90014-7.

Russell JB, Strobel HJ (1989) Effect of ionophores on ruminal fermentation. *Applied Environmental Biology* **55**, 1–6.

Schettini MA, Prigge EC, Nestor EL (1999) Influence of mass and volume of ruminal contents on voluntary intake and digesta passage of a forage diet in steers. *Journal of Animal Science* **77**, 1896–1904.

Scott JP (1962) Introduction to animal behaviour. In *The Behaviour of Domestic Animals*. (Ed. ESE Hafez) ch. 1. Williams and Wilkins, Baltimore.

Seoane JR, Baile CA, Martin HF (1972) Humoral factors modifying feeding behavior of sheep. *Physiology and Behaviour* **8**, 993–995.

Stangassinger M, Giesecke D (1986) Splanchnic metabolism of glucose and related energy substrates. In *Control of Digestion and Metabolism in Ruminants: Proceedings of the 6th International Symposium on Ruminant Physiology*. (Eds LP Milligan, WL Grovum and A Dobson) pp. 347–366. Prentice Hall, Englewood Cliffs.

Stubbs RJ (1999) Peripheral signals affecting food intake. *Nutrition* **15**, 614–625. doi:10.1016/S0899-9007(99)00098-2.

Suttle NF, Field AC (1969) Studies on magnesium in ruminant nutrition. 9. Effects of potassium and magnesium intakes on development of hypomagnesaemia in sheep. *British Journal of Nutrition* **23**, 81–90. doi:10.1079/BJN19690011.

Ternouth J (1990) Phosphorus in beef production in northern Australia. 3. Phosphorus in cattle: a review. *Tropical Grasslands* **24**, 159–169.

Ternouth JH, Beattie AW (1971) Studies of the food intake of sheep at a single meal. *British Journal of Nutrition* **25**, 153–164. doi:10.1079/BJN19710073.

Underwood EJ (1981) *The Mineral Nutrition of Livestock*. 2nd edn. Commonwealth Agricultural Bureaux, Slough, UK.

Van Nevel CJ, Prins RA, Demeyer DI (1974) On the inverse relationship between methane and propionate in the rumen. *Zeitschrift fur Tierphysiologie, Tierernahrung und Futtermittelkunde* **33**, 121–125.

Van Soest PJ (1965) Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. *Journal of Animal Science* **24**, 834–843.

Vermunt JJ, Visser RR (1987) Nitrate toxicity in cattle. *New Zealand Veterinary Journal* **35**, 136–137. doi:10.1080/00480169.1987.35413.

Villalba JJ, Provenza FD (2009) Learning and dietary choice in herbivores. *Rangeland Ecology and Management* **62**, 399–406. doi:10.2111/08-076.1.

Villalba JJ, Catanese F, Provenza FD, Distel RA (2012) Relationships between early experience to dietary diversity, acceptance of novel flavours and open field behaviour in sheep. *Physiology and Behavior* **105**, 181–187. doi:10.1016/j.physbeh.2011.08.031.

Waghorn GC, Adams NR, Woodfield DR (2002) Deleterious substances in grazed pastures. In *Sheep Nutrition*. (Eds M Freer and H Dove) pp. 333–356. CSIRO Publishing, Melbourne.

Waldo DR (1986) Effect of forage quality on intake and forage-concentrate interactions. *Journal of Dairy Science* **69**, 617–631. doi:10.3168/jds.S0022-0302(86)80446-5.

Waltner-Toews D, Meadows DH (1980) Urolithiasis in a herd of beef cattle associated with oxalate ingestion. *Canadian*

Veterinary Journal. La Revue Veterinaire Canadienne **21**, 61–62.

Ward JD, Spears JW, Gengelbach GP (1995) Differences in copper status and copper metabolism among Angus, Simmental and Charolais cattle. *Journal of Animal Science* **73**, 571–577.

Wright MJ, Davison DL (1964) Nitrate accumulation in crops and nitrate poisoning in cattle *Advances in Agronomy* **16**, 197–247. doi:10.1016/S0065-2113(08)60025-5.

Yang CM, Russell JB (1992) Resistance of proline-containing peptides to ruminal degradation *in vitro*. *Applied and Environmental Microbiology* **58**, 3954–3958.

17 Genetics and breeding

W.S. Pitchford

BREEDS, ENVIRONMENTS AND TARGET MARKETS INCLUDING BREEDING OBJECTIVES

The most successful animal breeding programs are managed by people with clear goals. The focus of this chapter is on technical aspects of breeding to provide tools for those seeking to achieve specific outcomes. Without a clear plan, what is written as a goal will, at best, be interesting information. So, before reading books, pause for a moment and dream big about the type of animals you would like to breed, what role you would like to play in industry (elite seedstock, multiplier, commercial, service provider) and then use this information to develop a plan for your goals – dreams without a plan are as bad as not having a dream.

In animal breeding, goals are termed 'breeding objectives'. Ponzoni and Newman (1989) outlined the steps in developing a beef breeding program as 1) define the breeding objective i.e. the traits to be improved, 2) choose selection criteria i.e. the characters to actually select, 3) organise the performance recording program, 4) use objective and subjective performance information to make selection decisions and 5) use the selected animals. The first step of defining the breeding objective formally converts dreams to goals.

The steps required to develop the breeding objective are to 1a) specify the breeding, production and marketing system, 1b) identify sources of income and expense in commercial herds. The aim of a stud is to maximise the profitability of its clients, 1c) determine the biological traits influencing income and expense and 1d) derive an economic value for each trait. Sometimes a clear economic value cannot be calculated and so a relative economic value is developed, based on the desired gain to be made.

Beef enterprise profitability is affected by a range of traits (Chapter 18). Market specifications are important determinants of the production system as they affect the desired amount of product (carcass weight) and the breeding strategy to maximise profitability. An anecdotal reason given by people reluctant to adopt management changes is that the 'goal posts are always changing'. While there are small changes between and within years, Australia's markets have been relatively stable for many years (Chapters 3, 11). They are best summarised as domestic and export requirements with export carcasses being older, heavier and fatter than domestic (Fig. 17.1).

There are large genetic differences between and within breeds in their ability to reach market weights with appropriate fat cover in the minimum time and/or lowest cost of feed (Cundiff *et al.* 2001, 2004; Pitchford *et al.* 2002). There are also breed differences in ability to handle environmental conditions in northern Australia (Chapter 9), where the primary issue is cattle tick resistance. Generally breeds with 50% *Bos indicus* breeding are fine, although some markets (e.g. Indonesian live export) and particularly harsh environments may require purebred Brahmans (Chapter 9).

For the domestic market, most breeds would have the breeding objective of producing maximum weight of beef at minimum cost. This would include cows getting in calf quickly after joining and calving early (ideally at two years of age), calving without assistance, rapid growth of the calf

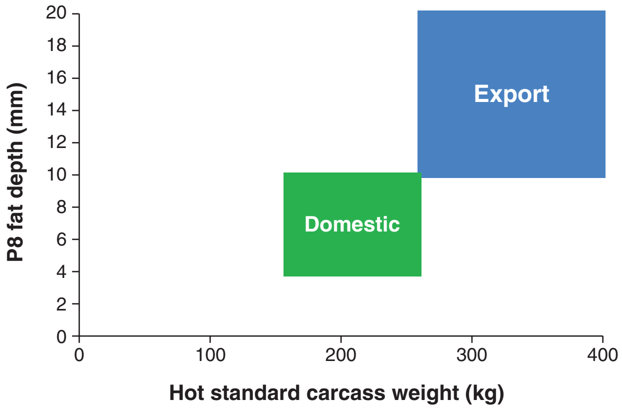


Figure 17.1: Approximate market specifications for prime Australian beef cattle. Source: Adapted from MLA (2012a); Chapter 3 (Table 3.1).

to weaning, minimum time to market weight (~400 kg liveweight), and carcass of optimal value by having sufficient fat cover and maximum retail beef yield. Costs include labour, fertiliser, animal health, transport and commission but, most importantly, feed for the cow and calf.

Export markets require animals to grow to over 600 kg and some markets (especially Japan and Korea) have large premiums for greater levels of marbling (intramuscular fat) (Chapter 8). Growing cattle to greater weights means the feed cost of the calf is greater relative to the cow and generally larger frame, 'later maturing' types are favoured for these markets. Thus, the profitability of the finisher sector becomes relatively more important and the traits affecting profitability of the breeder sector relatively less important than for the domestic market (Ponzoni and Newman 1989).

The beef breeds that marble the best are Angus, Murray Grey, Shorthorn and Wagyu (Pitchford *et al.* 2002; Wheeler *et al.* 2004). Wagyu is the term given to Japanese Black and it produces the most prized marbled beef. However, its production in Australian systems lacks profitability in the breeder herd, so there are few purebred herds. Angus has become the dominant breed in southern Australia because it has the largest number of animals performance recorded and has made the most genetic progress, although 76% of it through imported genetics primarily from the USA (Peter Parnell, CEO Angus Australia, pers. comm.). There is also the Japanese association of black cattle with preferred beef and great marketing. Angus cattle are profitable for the domestic market as well as the export market and many abattoirs now pay a premium for black cattle. Black coat colour and polled are both dominant traits and this has also helped the Angus. There is opportunity for other breed combinations to also be black and polled.

Cundiff *et al.* (2001, 2004) have characterised breeds over a very long period in the US Department of Agriculture (USDA) Germplasm Evaluation Project (Table 17.1).

CROSSBREEDING AND PURE BREEDING

Since breeds differ in traits and gene or allele frequencies, there can be advantages from crossing. Many cattle crossbreeding experiments have focussd on breed comparison and additive genetic effects (Cundiff *et al.* 1993) but fewer have been designed to formally test non–additive genetic effects (Pitchford *et al.* 1993). The USDA has tested formal crossing systems (Gregory *et al.* 1965; Wiltbank *et al.* 1967; Cundiff *et al.* 1974a, 1974b) in addition to extensive germplasm evaluation (Cundiff *et al.* 1993).

Dickerson (1969, 1973) defined the effects in crossbred livestock populations as direct (breed content), maternal (effect of dam breed), individual heterosis (effect of being crossbred), maternal heterosis (effect of having a crossbred dam) and recombination loss. Maternal effects have generally been assumed to be due to pre– and post–natal (milk) nutrient supply (Koch 1972; Splan *et al.* 2002). However, there are large differences between reciprocal crosses where calves from *Bos taurus* (Hereford or Angus) dams have much heavier birth weight than those from *Bos indicus* (Brahman) (Ellis *et al.* 1967). This is now known to be due to imprinting of specific genes (Xiang *et al.* 2013).

By using breeds in appropriate combinations, it is possible to exploit the effects of 'complementarity' (Fitzhugh *et al.* 1975). For example, a fertile high milk producing cow breed (e.g. Shorthorn or dairy cross) crossed to a high–growth well–muscled bull breed (e.g. Limousin). An example in southern Australian is the Hereford/Jersey cow crossed to a Charolais bull (Cuthbertson *et al.* 1990; Siebert *et al.* 1996). Other examples are where adaption traits in cows are important (e.g. Brahman) but bulls with superior growth or meat quality are used (e.g. Charbray or Brangus respectively). In a less extreme environment, it may be Santa Gertrudis cows crossed to purebred Charolais or Angus bulls.

One of the primary reasons for crossbreeding is to exploit hybrid vigour or heterosis, which is defined as the difference between the mean of the crossbred reciprocal crosses and the purebred mean. As discovered in the early days of corn breeding (Paterniani and Lonnquist 1963), the more distinct the crosses, the greater the heterosis effect. This also applies in cattle (Long *et al.* 1979).

Gregory and Cundiff (1980) summarised a comparison of Hereford, Angus and Shorthorns as purebreds, 2–way (F_1) crosses and 3–way crosses (purebred sire *x* F_1 dam). A

Table 17.1: Breeds grouped into biological types based on four criteria from the Germplasm Evaluation Program at MARC, Clay Center, Nebraska

Breed group	Growth rate and mature size	Lean:fat ratio	Age at puberty	Milk production
Jersey	X	X	X	XXXXX
Longhorn	X	XXX	XXX	XX
Hereford–Angus	XXX	XX	XXX	XX
Red Poll	XX	XX	XX	XXX
Shorthorn	XX	XX	XXX	XX
Galloway	XXX	XX	XXX	XXX
South Devon	XXX	XXX	XX	XXX
Tarentaise	XXX	XXX	XX	XXX
Pingauer	XXX	XXX	XX	XXX
Brangus	XXX	XX	XXXX	XX
Santa Gertrudis	XXX	XX	XXXX	XX
Sahiwal	XX	XXX	XXXXX	XXX
Brahman	XXXX	XXX	XXXXX	XXX
Nellore	XXXX	XXX	XXXXX	XXX
Braunvieh	XXXX	XXXX	XX	XXXX
Gelbvieh	XXXX	XXXX	XX	XXXX
Holstein	XXXX	XXXX	XX	XXXXX
Simmental	XXXXX	XXXX	XXX	XXXX
Maine Anjou	XXXXX	XXXX	XXX	XXX
Salers	XXXXX	XXXX	XXX	XXX
Piedmontese	XXX	XXXXXX	XX	XX
Limousin	XXX	XXXXX	XXXX	X
Charolais	XXXXX	XXXXX	XXXX	X
Chianina	XXXXX	XXXXX	XXXX	X

Increasing number of Xs indicates relatively higher values.
Source: Adapted from Cundiff *et al.* (1993).

practical measure of overall merit for a breeder herd is weight of calf weaned per cow joined. While it does not account for inputs such as feed, it does account for cow fertility, calving ease and calf survival, calf growth rate (direct) and the maternal effect (milk production) on weaner growth. The 2–way crosses averaged 8.5% more than the purebreds and the 3–way crosses were 14.8% greater than F_1, so 23.3% better than purebreds. This demonstrates the large effect of maternal heterosis on cow productivity. Industry has picked up on this, leading to famous quotes like 'running a herd without heterosis is like running a pick–up without oil!' (Jim Leachman 1994, http://www.leachman.com/htmlpages/history.htm#nogo). One of the difficulties of breeding beef cattle relative to corn, poultry or pigs is the low reproductive rate of cows (<1 offspring/year). This means that it is not feasible to develop crossbred cows and widely distribute them as superior dams. Sheep also have low reproduction rates but, because they produce wool, Border Leicester rams can be crossed over Merino ewes to produce a superior F_1 crossbred ewe. The cattle equivalent was to produce dairy cross cows which were popular in southern Australia when premiums were paid for vealers (sold for slaughter immediately after weaning) and carcass weight requirements were lower. However, since the 1990s, carcass weight requirements have increased to improve processing efficiency and so vealer production has become rare. There is therefore little value in the additional milk produced by dairy cross cows and the high energy requirements of doing so generally makes them less profitable than purebred beef breeds. That said, it is hard to beat a Jersey cross cow mated to a large European beef breed for weaner production (Cuthbertson *et al.* 1990).

The challenge of optimising heterosis in the cow herd is substantial (Gregory and Cundiff 1980). Large herds could use formal 3–way crosses, but would have to maintain a purebred population to produce F_1 cows. Alternatives to this are to use F_1 bulls, rotational crossing or development of composite cattle. Newman *et al.* (1997) developed a decision support tool to aid crossbreeding programs for tropical adapted cattle. More refined systems have been developed but rely on good multi–breed EBVs (estimated breeding values), which remain a serious limitation (Johnston *et al.* 2003). Hayes and Miller (2000) used a linear programming approach to demonstrate selection strategies to utilise within– and across–breed genetic variation. Kinghorn (2011) has developed more efficient methods using a genetic algorithm.

F_1 bulls crossed to F_1 cows produce the second filial generation, termed F_2, $F_2 \times F_2 = F_3$ and so on. In the absence of inbreeding, the F_2 and further crosses are expected to have half the level of individual heterosis of the first cross (F_1) although they have full maternal heterosis since they are from F_1 dams. Ongoing use of F_1 bulls (e.g. $F_1 \times F_3$) would also result in half the individual and maternal heterosis. Thus, on average this system would be expected to produce 23.3/2 = 11.6% more calves weaned than the purebreds. One of the problems of using F_1 bull system is the large amount of recombination which, depending on the breed used, could lead to large variation in coat colour and possibly performance of progeny, making marketing difficult. Ideal breeds for an F_1 bull system could be the Simmental and Polled Hereford because of similar markings and different breed type. In a tropical system, Brahman and Murray Grey could be used to produce F_1 bulls that combine adapted traits from the Brahman and superior meat quality and reproduction from the Murray Grey, have ideal coat colour, are polled and utilise heterosis.

A rotational cross can be done with two or more breeds and the greater the number of breeds involved, the greater the amount of heterosis. Since purebred bulls are common, the most likely system would be to buy in bulls and cross the progeny of one sire breed to the other sire breed (Fig. 17.2). Given that most crossbreeding systems use purebred sires, the ongoing success of the crossbreeding systems is dependent on genetic improvement within the pure breeds to be utilised. With two breeds involved, the level of heterosis retained would be 67% (Eqn 17.1), so 67% of 23.3% would be a 15.6% increase in weight of calf weaned per cow joined. Thus, a 3–breed rotational cross would retain 86% (6/7ths) of the potential heterosis. Rotational crosses work best with breed of similar type (size, milk, muscularity), such as Angus and Hereford.

$$\text{Rotational Heterosis} = \frac{2^n-2}{2^n-1} \qquad \text{(Eqn 17.1)}$$

where n is the number of breeds in the rotational cross.

A composite breed starts with crossing two breeds, but then involves *inter se* mating in the same way as producing an F_2 and subsequent crosses. Thus, the level of heterosis retained, assuming no inbreeding, would be 50%. However, if there are more breeds involved, the level of heterosis retained is greater (Eqn 17.2). Thus, a 3–breed composite would retain 67% and a 4–breed 75% of the heterosis.

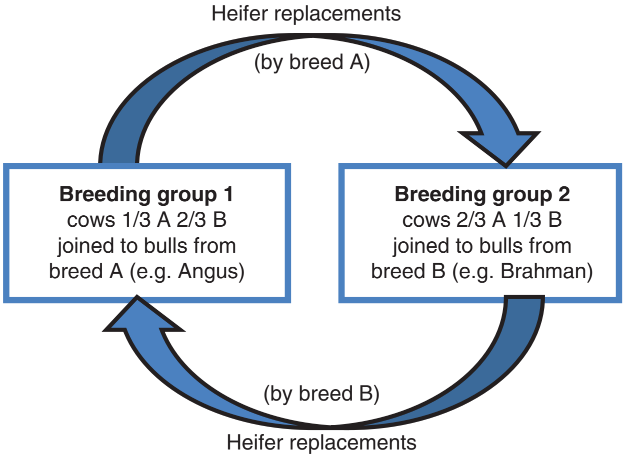


Figure 17.2: Schematic to demonstrate a 2–breed rotational cross.

Many of the large pastoral companies in northern Australia (Chapter 21) have developed composite cattle breeds, often based on a 4–breed cross. However, these have been designed to utilise direct combinations of breeds rather than utilisation of heterosis, which effectively is a bonus. An example is the program of S. Kidman and Co that developed the 'Coolibah Composite', comprising 1/4 Brahman (heat, tick and drought tolerance), 1/4 Charolais (growth, muscling and light colour), 1/4 Murray Grey (early maturity, fertility, meat quality and light colour) and 1/4 Tuli (tropically adapted *Bos taurus*) (Beef CRC 2012).

$$\text{Composite Heterosis} = \frac{n-1}{n} \qquad \text{(Eqn 17.2)}$$

where n is the number of breeds in the development of the composite population.

While heterosis results in increased growth and reproduction, there are negligible effects on carcass quality (retail beef yield and marbling). Thus, heterosis in the cow herd is relatively more important for producers targeting the domestic market than export. A summary for evaluating the value of heterosis in production systems is given in Table 17.2.

COMMERCIAL BULL SELECTION, INCLUDING STRUCTURAL ASSESSMENT AND PRICE

Once the breed of bull is chosen, purchasing decisions must be made. Issues include the traits to be targeted and how much to pay for a superior bull. Since bulls are purchased for their ability to produce good offspring, the key traits are serving capacity and their EBV for traits in the

Table 17.2: Sources of genetic differences

		Between breeds (i.e. can you choose a better breed for the key profit factors – these figures assume starting with a British breed base)			Hybrid vigour – interaction between breeds	
Traits of economic importance	**Within breed (i.e. selecting the best within one breed – the variation is calculated as the top 10% of the breed compared to the bottom 10% in a group Breedplan summary)**	**BB (is there a better British breed)**	**Euro (is there a Euro breed better than the base British breed)**	**Bos I (is there a Bos I breed better than the base British breed)**	**BB/BB or BB/ Euro**	**BB/Bos I or Euro/Bo. I**
Growth	✓	✓	✓✓	✓✓	✓	✓✓✓
Reproduction	✓	✓	✓	✓	✓	✓✓
Carcass – quantity (yield)	✓	✓	✓✓✓	×	0	0
Carcass – quality (marbling)	✓	✓	×	×	0	0

✓ = ~5% gain, ✓ = 2.5% gain, × = 2.5% loss, 0 = zero gain.
Source: MLA (2012b).

selection index. No premium should be paid for fat cover, how well a bull has been clipped or how he behaved in a sale ring – an environment he is likely to face only once in a lifetime.

Serving capacity depends on the bull's structure, soundness or health of reproductive organs and testicular size (Chapter 14). Since most bulls (not terminal sires) breed heifers that remain in the herd, structural faults should be avoided. While breeding values for structural traits are being developed, phenotypic selection is recommended. Most breeds do not have genetic parameters for structural traits that are not usually highly heritable (Morris *et al.* 1985). Scoring systems for leg and feet structure have been developed (Fig. 17.3). For most traits with mid–range optimums, 3–7/9 should be fine for commercial bulls or 4–6/9 for sires of bulls (generally in studs). Recent analysis of these traits has demonstrated that many are moderate–highly heritable; they will be expressed as a percentage of desirable scores so breeders can simply select for higher values (Jeyaruban *et al.* 2012).

Traits that can be measured and affect profitability should have EBVs provided by Breedplan. EBVs are adjusted for average management of a group, sex of calf, age of dam and age of calf when measured. From research projects, the heritability of traits and genetic relationships between traits is known and so these can be taken into account to improve the accuracy of prediction. Genomic tests based on variation in an individual's DNA are developing and will greatly add to the accuracy of EBVs in young bulls, especially for traits that are hard to measure or can only be measured on females (Johnston *et al.* 2012; also discussed later in this chapter).

The simplest way to value a bull is on his growth EBVs. If supplying the domestic market, then 400 day weight could be the main trait. An Angus bull born in 2010 and in the top 10% of the breed would have an EBV of +86 compared to breed average +70 (Table 17.3). The average of the first 200 records was 0, so the breed has made 70 kg genetic gain in 400 day weight since 1985. The difference between a bull on the top 10 percentile and an average bull is 86–70 = 16 kg. Since half of this superiority is passed on to his progeny, at 400 days of age, calves from the top 10% bull would genetically be 16/2 = 8 kg above those from the average bull. The economic value of this would depend on the value of the extra growth and the number of progeny. If the value was $1.80/kg and there were 100 calves, the extra value would be 8 kg/calf × $1.80/kg × 100 calves = $1440. Put simply, if a bull buyer paid $1440 extra for the bull, then they would only break even on the deal.

If a bull that is so much better than average only makes $1440 more than an average bull, an obvious question is why greater premiums are being paid? There are at least four reasons for this: 1) livestock production is a function of more than one trait, 2) the bull also has daughters that remain in a breeding herd for many years and so the benefits get multiplied over time, 3) if the bull is single–sire mated then he is less likely to suffer penile damage and can have more than 100 progeny, 4) if the bull was purchased by a stud and had semen collected and/or became a sire of bulls, his reproductive rate is effectively increased which again multiplies the superiority.

The number of expressions of the trait in progeny becomes a key issue. While the number of progeny could be 100, half of those are heifers where the extra value of

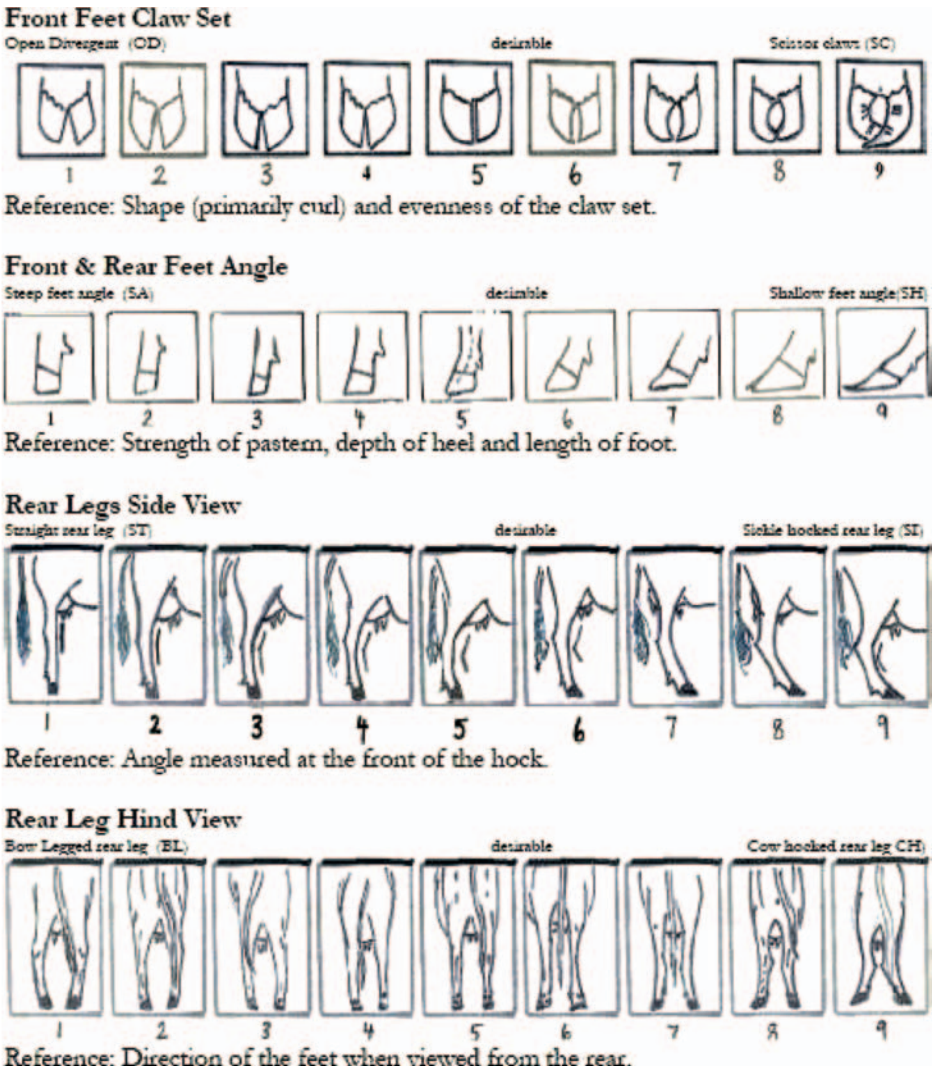


Figure 17.3: Examples of structural trait assessment. Source: Breedplan (2012a).

the weight is not realised, but they have steer calves over multiple years. Accounting for the total number of decedents and the proportion of genes inherited from the superior sire (Hill 1974), the number of expressions of the trait in a commercial herd could be 200; in a stud herd that sells bulls, it could be very large. At 200 weighted expressions, the superiority would increase to 16 kg × \$1.80 × 200 = \$5760.

Anecdotal experience from stud breeders suggests they capture only 10% of this superiority, so the commercial breeder is capturing 90% of the benefit. However, this is spread over a long time horizon. If the benefit is discounted by 10% per year, then the 200 expressions would be equivalent to ~80 expressions. So, from a weighted and discounted expressions approach, the superiority would be far less, 16 kg × \$1.80 × 80 = \$2304.

The best way to combine information across traits is to formally develop a breeding objective and calculate economic values on traits affecting income and expense. This has been done for most breeds using a program called BreedObject (Barwick and Henzell 2005). Index values are in dollars per cow joined, so a 2010 top 10% Angus bull for the long–fed index would have a value of \$120 compared to the average of \$94, a difference of \$26. In this case, if the top 10% bull had 100 progeny he would be worth 26 × 0.5 × 100 = \$1300 more than an average bull, possibly more if total number of expressions across male and female progeny are considered.

When selecting bulls at a sale, a good strategy before going to the sale is to use the index value to select a group of potential bulls, check individual trait EBVs are not too extreme and complement the cows to be joined, then once

Table 17.3: Breedplan EBVs for six 2010 drop Angus bulls in the top 10% for 400 day weight and long–fed index

Name/ID	Calving ease (direct) (%)	Calving ease (daughters) (%)	Gestation length (days)	Birth weight (kg)	200 day weight (kg)	400 day weight (kg)	600 day weight (kg)	Mature cow weight (kg)	Milk (kg)	Scrotal size (cm)	Days to calving (days)	Carcass wt (kg)	Eye muscle area (cm^2)	Rib fat (mm)	Rump fat (mm)	Retail beef yield (%)	IMF (%)	Long–fed/ CAAB index	Heavy grass–fed steer index	Short–fed domestic index	Terminal index
Carabar Expedition F100(AI)(ET)	+1.4	+1.0	–3.0	+5.1	+45	+86	+111	+95	+15	+0.2	–1.9	+69	+7.8	–1.7	–1.7	+1.9	+1.2	+$120	+$101	+$88	+$90
Denbar F216(APR)(AI)	–1.8	–1.7	–4.4	+5.6	+46	+86	+107	+89	+15	+2.0	–3.4	+56	+6.8	+0.5	+0.7	+1.0	+1.9	+$120	+$93	+$83	+$85
Pathfinder Infinity F83(AI)	+0.4	+0.6	–4.7	+4.2	+45	+86	+111	+111	+7	+2.4	–3.7	+68	+6.8	–0.1	–0.1	+1.0	+1.9	+$120	+$97	+$82	+$87
Booroomooka Equator F369(AI)	–0.8	–0.3	–3.8	+4.9	+46	+86	+110	+92	+10	+2.0	–2.8	+63	+5.5	–0.3	+0.2	+0.4	+1.9	+$120	+$90	+$78	+$82
Rennylea F336	–3.7	–1.1	–1.7	+7.4	+47	+86	+107	+102	+14	+2.0	–3.3	+62	+6.7	+1.2	+1.1	+0.1	+2.5	+$120	+$85	+$76	+$81
Moogenilla Infinity F33(APR) (AI)	+0.2	+0.8	–4.8	+4.6	+46	+86	+107	+105	+7	+2.9	–5.2	+62	+3.7	+0.4	+1.9	–0.8	+2.6	+$120	+$85	+$74	+$74
Breed avg EBVs for 2010 born calves	+0.0	+0.3	–2.9	+4.5	+38	+70	+89	+82	+12	+1.4	–3.0	+50	+3.6	–0.1	+0.0	+0.3	+1.0	+94	+77	+67	+68

Source: Breedplan (2012b).

at the sale check for structural faults. The bulls listed in Table 17.3 demonstrate that even when their EBVs for 400 day weight and long–fed index are the same, EBVs for carcass weight can range from 56–69 kg and sometimes could be of quite different ‘maturity type’. Commercial buyers should go with plenty of options and logical fallback positions because it often seems that stud breeders or commercial breeders are targeting the same bulls. Optimisation tools are being developed to help buyers optimise investment and returns when working through bulls catalogues before sales (e.g. ‘Bullaway’, Cottle, pers. comm.).

One of the valid criticisms of young bull EBVs is that they lack accuracy. The accuracy is the correlation between the EBV and the true breeding value which cannot actually be measured. Accuracy improves as information is collected through measurement and relatives’ records. High accuracy can only be achieved by progeny testing, although this should not limit genetic progress in beef cattle because most economically important traits can be measured on the live animal (Goddard 2009). The average Angus yearling bull from well–recorded herds with measurements but no progeny has an accuracy of 400 day weight EBV of around 0.65 and for traits like female reproduction (days to calving), <0.40.

Often commercial breeders need multiple bulls so, rather than focus too much on individual bulls, the aim is to achieve maximum index value of a team of bulls for minimum price. The advantage of this approach is that the accuracy of average EBVs for a team of bulls is greater than the average accuracy of individual bulls. This occurs by minimising errors in estimation. Even small teams of three or four bulls can have accuracies equivalent to progeny–tested bulls for low heritability traits (Fig. 17.4). The improvement with related bulls is lower, but still substantial. Indexes generally have low accuracy (Barwick *et al.* 2012) but are useful because they are highly correlated with the desired phenotype. Bull team accuracy for an index is close to the 30% line in Fig. 17.4.

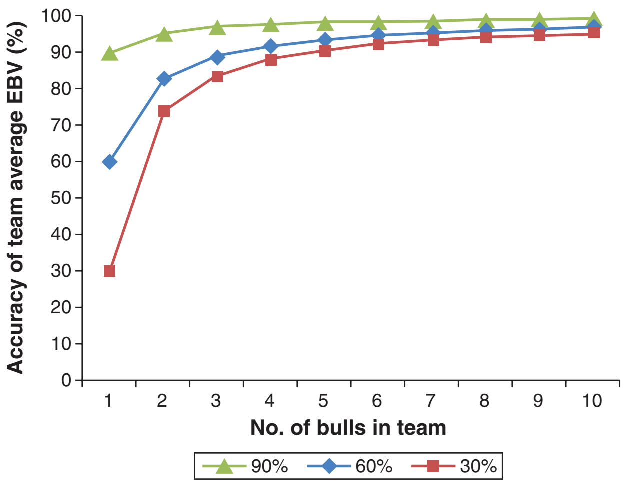


Figure 17.4: Accuracy of team average EBV with three initial accuracies (0.9, 0.6, 0.3). Source: Adapted from Lohuis and Smith (1994).

PUREBREEDING: MAXIMISING GENETIC PROGRESS

Choice of selection criteria including use of Breedplan

Breeding objective and selection criteria traits for Angus are given in Table 17.4. These traits are also relevant for other breeds.

The selection criteria listed in Table 17.4 are then combined into three indices reflecting different breeding objectives: 1) the long–fed or Certified Australian Angus Beef (CAAB) index (heavy, marbled carcasses), 2) a supermarket index (domestic carcasses) and 3) a northern Australia terminal index (crossing Angus bulls to

Table 17.4: Traits and characters for Angus cattle

Trait in the breeding objective	Character in selection criteria
Calving ease – direct (%) Calving ease – maternal (%)	Calving ease – direct (%) Calving ease – daughters (%) Gestation length (days) Birth weight (kg)
Cow weaning rate (%)	Days to calving (days) Scrotal size (cm)
Sale liveweight – direct (kg) Sale liveweight – maternal (kg)	200 day weight – direct (kg) Milk (kg) which is 200 day – maternal 400 day weight (kg) 600 day weight (kg)
Dressing percentage (%) Saleable meat percentage (%) Rump fat depth (mm) Marbling score	Carcass weight (kg) Eye muscle area (cm^2) Rib fat depth (mm) Rump fat depth (mm) Retail beef yield (%) Intramuscular fat (%)
Cow survival rate (%) Cow weight (kg)	Mature cow weight (kg)
Residual feed intake – post–weaning Residual feed intake – feedlot Residual feed intake – cow	Net feed intake (kg) Mature cow weight (kg)

Source: Barwick and Henzell (2005 and pers. comm.).

Brahman type cows with all progeny sold). It is important to note that even for the long–fed index, there is a large emphasis on traits related to breeder herd profitability. This is the case even across diverse environments and breeds where importance is placed on calving ease and growth. The biggest differences between indices is for days to calving and intramuscular fat (Fig. 17.5). In addition to the selection criteria presented, the Limousin breed has developed EBVs for docility based on a formal scoring system (McDonald 2006) and tropically adapted breeds have an EBV for flight speed (seconds, Burrow *et al*. 1988) and tenderness (kgF) based on a genomic test (Johnston *et al*. 2008). Structural soundness EBVs are currently under trial, involving collection of data and estimating genetic relationships with other traits in the breeding objective. Tropical adaption traits that are important to *Bos indicus*–derived breeds are not currently measured or scored and so do not have EBVs. Breeders rely on across–breed rather than within–breed variation for adaption traits and cull those with obvious faults.

Performance recording system including structural assessment, management of cohorts, independent culling levels

Ideally, calves should be 'mothered up' and tagged, with calving ease, birth weight and sex recorded within 24 hours of birth (Fig. 17.6). If birth weight and calving ease are not measured, then EBVs are still assigned, but

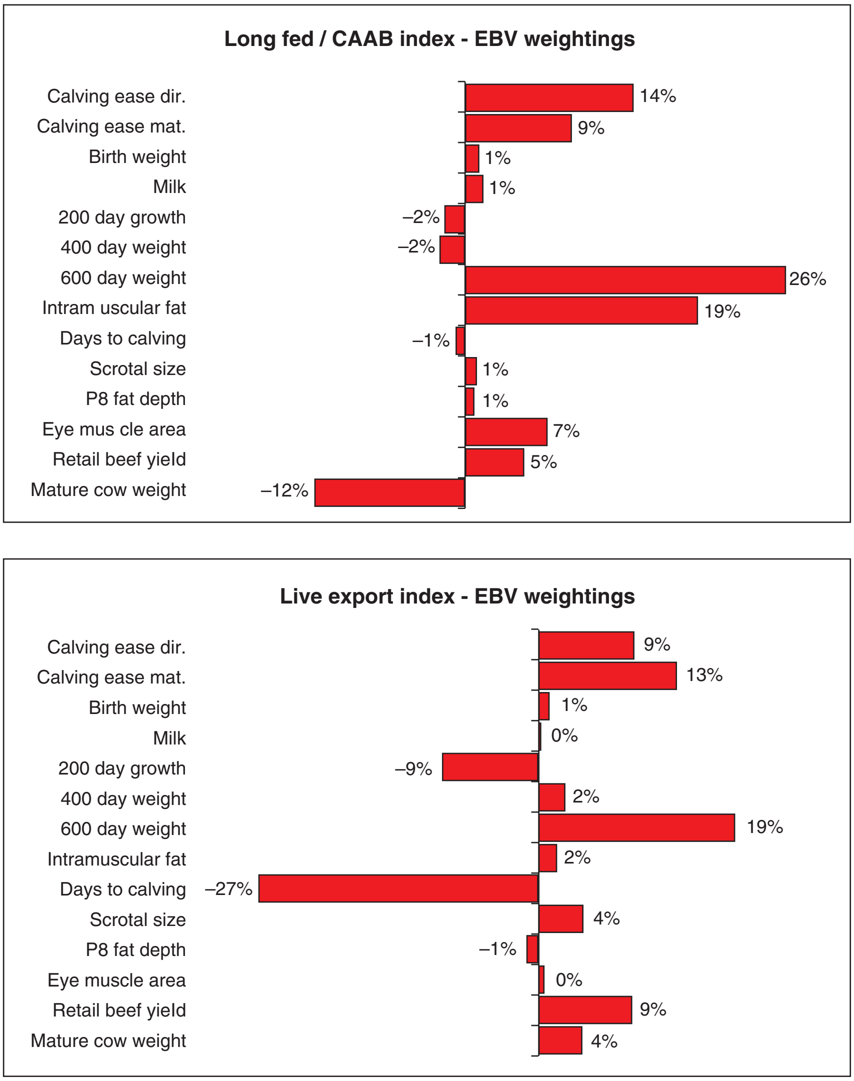


Figure 17.5: EBV weightings (relative economic values that sum to 100%) for two very different markets: Angus long–fed and Brahman live–export. Source: Breedplan (2010, 2011).

they are based on genetic correlations with later growth traits. Thus, it is impossible to identify 'growth curve benders' – those with low birth weight and high growth rate EBVs. At weaning, calves are weighed and obvious 'poor doers' and those with structural faults are culled from the breeding program, i.e. they may be sold, castrated if male and/or grown out to sell at a later date. It is common to cull 5% of calves at this stage. If calves are grown out for sale but retained in the same management groups, they may still provide valuable information for EBVs on relatives such as half–sibs for later weights, docility scores and flight speed.

Feed efficiency tests could be conducted in the post–weaning period when bulls are commonly fed well before sale. No Australian studs currently measure feed efficiency on heifers, but some do on bulls (e.g. Coota Park 2012). The tests follow standard industry protocols (Exton 2001). There is a three–week adjustment period then a 10–week formal test with cattle weighed weekly and feed measured at least that often. Electronic feeding systems have been developed, with the current most popular version the Growsafe system (Growsafe 2012). The primary aims of the feed efficiency testing is to breed steers that are more efficient in feedlots and cows that require less feed on pasture. An electronic feedbin system for measuring feed efficiency at pasture, based on plant markers, is under development by Proway Livestock and Sapien Technology (Cottle and Romero 2013).

At ~400 days, heifers and bulls are weighed, ultrasound–scanned for eye muscle area, fat depth at rib (12/13th) and rump (P8) sites and intramuscular fat. They are also assessed for structure and another 5% may be culled. Of the remaining heifers, all are likely to be joined either naturally or more commonly in studs making the most genetic progress, have oestrus synchronised and be artificially inseminated and naturally mated as backup, as only 50% are likely to conceive to a single AI program. At least six weeks after the mating period has finished, heifers are often pregnancy–tested; if found not to be pregnant, are sold for slaughter or sometimes mated and tested again and sold as commercial heifers.

The top 5% of bulls are likely to be retained in the stud for use as yearling bulls (first progeny born at two years). It is common for the other 85% to be grown out to be sold as two–year–old bulls to other studs and commercial clients. Before being sold as working bulls, in northern Australia it is common to have a bull breeding soundness examination (BBSE) (Chenoweth *et al.* 2010). The most elite young bulls may have semen collected before they are used to ensure it is free of sexually transmitted diseases that could be contracted after its use.

Population size to minimize inbreeding

Since there are generally far fewer bulls than cows in the breeding herd, genetically the herd is effectively smaller than if there were equal numbers. The effective number of individuals in a closed population (N_e) is given by equation 17.3:

$$N_e = \frac{4sd}{s+d} \approx 4s \qquad \text{(Eqn 17.3)}$$

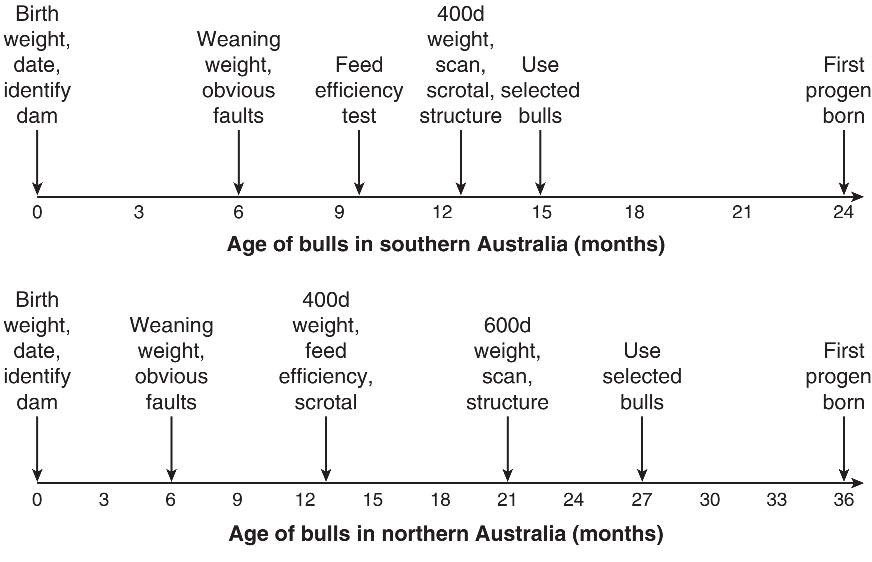


Figure 17.6: Timeline of performance recording on common stud herd in southern and northern Australia.

where N_e is the effective population size, s is the number of sires and d is the number of dams. As the number of dams per sire increases, the effective population size approaches $4s$ and so in most beef seedstock herds and breeds is driven by the number of sires used.

The reason to maximise the population size is to minimise inbreeding and maximise genetic variation for selection gains. The change in inbreeding is given the symbol ΔF and the general recommendation is to keep it below 1% per generation (Simm 1998). Inbreeding depression is caused by increasing levels of homozygousity of undesirable alleles.This leads to lower production and is potentially lethal (MacNeil *et al.* 1989).

$$\Delta F = \frac{1}{2N_e} \approx \frac{1}{8s} \qquad \text{(Eqn 17.4)}$$

Given that N_e is approximately $4s$ when there are many dams per sire, the inbreeding is also related to the number of sires used. Thus, to ensure that ΔF stays below 1% per generation, the number of sires used in a closed herd should be at least 13 (>12.5).

In theory, this means that a stud with a mating ratio of 40 cows per bull could be closed to introductions of genetic material if it had 13 bulls and 520 cows – the recommended minimum size population for this purpose. In practice, most herds import unrelated sires through purchasing bulls or semen. This is important not only for maintaining genetic diversity, but also to provide genetic links between herds to allow genetic evaluation for estimation of across–herd EBVs.

It is likely that some inbreeding will occur even in relatively large seedstock herds. A common pedigree is presented (Fig. 17.7). The inbreeding coefficient on an individual is half of the additive relationship between the parents (Table 17.5). While inbreeding should be avoided, occasional close breeding is probably acceptable and a common recommendation is to keep inbreeding coefficients of individuals <10% so the coancestory (of genes) relationship between any parents should be <0.2. For example, progeny of mating H and F would have an inbreeding coefficient of half the relationship (0.125), so is 6.25% (= 1/16) which would be considered acceptable. Where this could be a problem is when bull B is a carrier of a genetic defect, there is a 25% probability that H is a carrier and a 50% probability that F is a carrier. If two carriers mate, the probability of an affected progeny is 25% (1/4). Thus, the probability of an affected progeny from mating H and F, if B is a carrier, is 0.25 × 0.5 × 0.25 = 0.03125 (1/32).

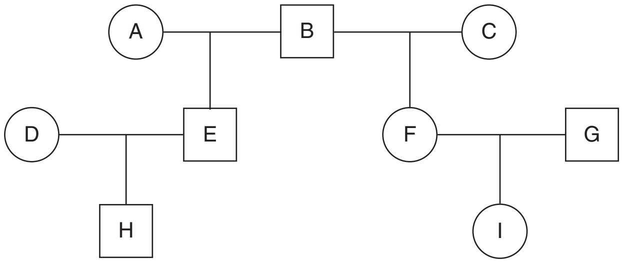


Figure 17.7: Common pedigree. Squares = males; circles = females.

Herd structure to maximise genetic progress

Genetic progress is calculated using the 'breeder's equation' (Eqn 17.5):

$$\Delta G = \frac{i_P \acute{o}_A \, Accuracy}{L} = \frac{i_P \acute{o}_P \, h^2}{L} = \frac{Sh^2}{L} \qquad \text{(Eqn 17.5)}$$

where ΔG is the change in genetic value or response to selection in units of the trait per year, i_P is the intensity of selection based on the proportion of parents selected (P),

Table 17.5: Relationship matrix based on the pedigree in Fig. 17.7

	A	B	C	D	E	F	G	H	I
A	1	0	0	0	0.5	0	0	0.25	0
B	0	1	0	0	0.5	0.5	0	0.25	0.25
C	0	0	1	0	0	0.5	0	0	0.25
D	0	0	0	1	0	0	0	0.5	0
E	0.5	0.5	0	0	1	0.25	0	0.5	0.125
F	0	0.5	0.5	0	0.25	1	0	0.125	0.5
G	0	0	0	0	0	0	1	0	0.5
H	0.25	0.25	0	0.5	0.5	0.125	0	1	0.0625
I	0	0.25	0.25	0	0.125	0.5	0.5	0.0625	1

Table 17.6: Population structure with bulls and cows culled young or old

Age when progeny born (years)	2	3	4	5	6	7	8	9	10	Total
Herd 1										
Number of bulls	5	5	5	5	5					25
Number of cows	195	166	141	120	102	87	74	63	52	1000
Herd 2										
Number of bulls	25									25
Number of cows	314	267	227	192						1000

σ_A is the amount of genetic variation in the traits (additive genetic standard deviation), *Accuracy* is defined as the correlation between the EBV and the true breeding value, σ_p is the phenotypic standard deviation and L is the generation interval.

A special case of the equation exists when selection is based solely on a single phenotypic record on the animal so the accuracy is the square root of the heritability (h^2). Thus, the equation simplifies to be a function of σ_P. Further simplifying, S is the difference in mean between the selected individuals to be parents and the mean of the population they came from (selection differential). A simple herd structure and response to selection demonstrates the value of turning generations over faster (Tables 17.6, 17.7).

In terms of population structure, the way to maximise genetic progress is to maximise selection intensity relative to generation length. There is a tradeoff between these, so it is important to maximise the ratio rather than either component. That said, the major genetic gain comes from the sire. In the example above, in Herd 1 the male ratio was 0.67 compared to 0.18 for females and in Herd 2 was 1.03 relative to 0.13. In this example, the value of turning over generations faster was an extra 18% annual genetic progress.

Table 17.7: Calculation of annual genetic gain in herds with long and short generation intervals

Calculations	Herd 1	Herd 2
Proportion of males selected, P_M	5/425	25/425
Intensity of selection in males, i_M	2.66	2.06
Average age of sire, L_M	4.00	2.00
Male ratio, i_M/L_M	0.67	1.03
Proportion of females selected, P_F	195/425	314/425
Intensity of selection in females, i_F	0.88	0.42
Average age of dam, L_F	4.95	3.30
Female ratio, i_F/L_F	0.18	0.13
Average intensity of selection, i	1.77	1.24
Average age (years), L	4.48	2.65
Response to selection, ΔG (\$/year)	\$3.16	\$3.74

The reason more gain is from the sires is that they have far more progeny, so fewer of them are required as replacement parents for the next generation. When fewer are required as parents, the chosen ones can be 'more superior' than the unselected male population. Also, a higher reproductive rate means that gain is maximised when generation interval is minimised (Fig. 17.8). In fact, older bulls should only be used if they are proven superior, which usually means they have increased accuracy of EBVs because of the inclusion of data from progeny. The rate at which old bulls will be replaced by better young bulls depends on the accuracy of EBVs on young bulls. Given that genomic selection will increase the accuracy of EBVs of young bulls, it is expected that, in the future, leading sires will be replaced by superior sons more rapidly than they are now.

To summarise, herd structure should be designed in a way that maximises two factors:

1. use of young progeny to speed generation turnover;
2. multiplication of animals with demonstrated superior EBVs.

Use of reproductive technologies

Reproductive technologies (Chapter 14) enable a greater number of offspring per sire or dam, which greatly increases selection intensity and can also decrease

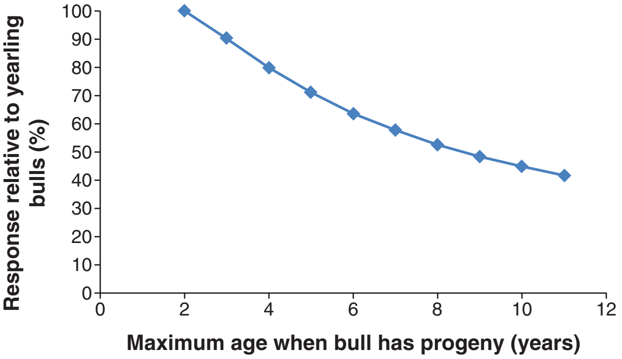


Figure 17.8: Relationship between genetic progress and number of years in the herd.

generation interval, both leading to significantly increased rates of genetic progress. Artificial insemination (AI) can lead to extremely large numbers of progeny and potential for distributing superior genetics internationally as well as across herds. From the stud owner's viewpoint, sales of semen from superior bulls can be extremely profitable. From the user's viewpoint, there is the double benefit of using superior sires and providing genetic links between herds, thus allowing Group Breedplan estimation of breeding values, which can also be international.

Multiple ovulation and embryo transfer (MOET, Gordon 2003) is a way of overcoming the greatest limitation to genetic progress in cattle – a low female reproductive rate. It is not inexpensive although, if using expensive semen, the cost per live calf can be lower than with using AI.

In breeding programs animals should be culled on EBV, not simply on age. However, to demonstrate the effect of reproductive technologies on genetic gain a third herd with a new structure is presented (Table 17.8). The additional genetic gain in Herd 3 is substantial, more than double that with normal reproductive rates (122% additional gain). Adding AI led to an extra 16% gain, but the major lift in annual genetic gain cam from the reproductive technologies that overcome low female reproductive rate. Again, selection should not be based solely on age, so cows with high EBVs are the ones that should be multiplied.

Assume the genetic standard deviation in the index is \$20, which is equivalent to a phenotypic standard deviation of \$50 if the heritability of the index is 0.16 (accuracy 0.40). Using MOET, 850 calves could be generated from 100 donor cows with 1000 recipients so, genetically, the herds are a 10th the size of Herds 1 and 2.

Table 17.8: Calculation of annual genetic gain in herds utilising MOET and AI

Calculations	Herd 3	Herd 4
Cows per bull	40	400
Proportion of males selected, P_M	2.5/425	0.25/425
Intensity of selection in males, i_M	2.84	3.51
Average age of sire, L_M	2	2
Male ratio, i_M/L_M	1.42	1.76
Progeny per cow per year	8.5	8.5
Proportion of females selected, P_F	100/425	100/425
Intensity of selection in females, i_F	1.31	1.31
Average age of dam, L_F	2	2
Female ratio, i_F/L_F	0.66	0.66
Average intensity of selection, i	2.08	2.41
Average age (years), L	2	2
Response to selection, DG (\$/year)	\$8.32	\$9.64
Gain relative to previous best	122%	16%

Juvenile *in vitro* fertilisation and embryo transfer (JIVET, Armstrong *et al.* 1992) enables additional gains in improved intensity of selection and reduced generation interval. Heifer calves have immature ova harvested at two to three months of age. These are then matured so they are no longer juvenile, are fertilised *in vitro* and the resulting embryos are grown to eight– to16–cell stage then implanted into recipient cows. It is possible for a heifer to have calves born by the time she is one year of age. In theory, this could continue, but the limitation comes in the accuracy of selection. JIVET is only worthwhile if the heifers used are genetically superior. For within–breed improvement (rather than breed substitution), breeding decisions can be made based on mid–parent EBV. However, for subsequent generations the accuracy of this becomes too poor. Good genomic tools for increasing accuracy could overcome this (Johnston *et al.* 2012).

Use of DNA markers: major genes, pedigree testing, genomic selection

As shown above, in addition to maximising selection intensity and minimising generation interval, the other driver of genetic improvement is accuracy of selection. The most common measure of accuracy is the correlation between the EBV and the true breeding value. For a common trait like liveweight, the accuracy of a single measure on the individual is the square root of the heritability (e.g. $\sqrt{0.36} = 0.6$). Selection indices are commonly measured with low accuracy, but are valuable because they are most highly correlated with the desired phenotype. The best way to achieve accurate EBVs is to have progeny records (Fig. 17.9). For low–heritability traits, many progeny are needed. For example, if the heritability is 0.1, then 166 progeny would be required to achieve an EBV accuracy of 0.9.

$$r_{EBV,A} = \sqrt{\frac{ph^2}{4+(p-1)h^2}} \qquad \text{(Eqn 17.6)}$$

where $r_{\mathrm{EBV,A}}$ is the accuracy, p is the number of progeny and h^2 is the heritability.

For traits that are difficult to measure or of low heritability, progeny–testing programs can be cost–effective. In addition to providing accuracy, they strengthen genetic links between herds and thus increase the accuracy of EBVs for related cattle. Examples of traits that are difficult

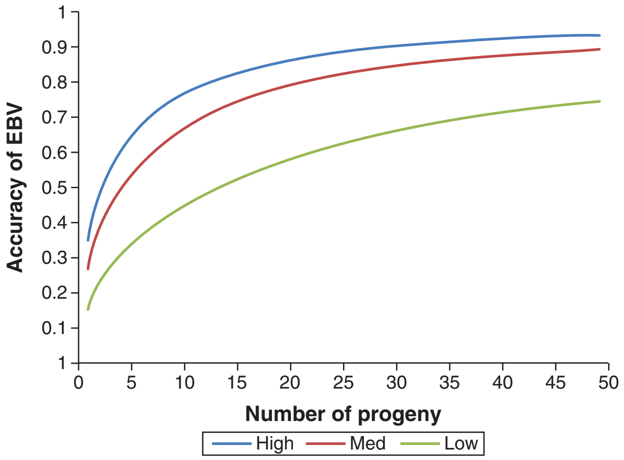


Figure 17.9: Effect of number of progeny on accuracy of EBV for high (0.5), medium (0.3) and low (0.1) heritability traits. This assumes information from progeny only, whereas in most breeding programs there is information on relatives and some measures on the individual that all add accuracy to the EBV.

to measure but have high economic value are heifer conception rate, where variation can be masked by use of oestrus synchronisation for AI programs, and eating quality traits such as marbling score and tenderness in steers. The problem with progeny–testing programs is that limited numbers of sires can be tested and it takes significant time for the information to be produced, so what is gained in accuracy can be lost in generation interval. However, while there may be negligible gain within a herd with a good performance recording program, the advantage for a breed is to confidently identify sires that can be multiplied using AI.

DNA testing provides the opportunity to get genetic information on individuals as soon as a DNA sample can be collected. In theory, this can be done from early embryos and so selection could be done in a petri–dish as part of a MOET or JIVET program (Armstrong *et al.* 1992). In practice, harvesting cells from embryos affects their viability and so DNA samples are more likely collected after birth, when calves are first tagged. DNA can be collected as blood, from an ear notch or from plucked hair follicles. DNA is extracted from the sample then genotyped using a range of systems. The most common system is to genotype for single base changes (single nucleotide polymorphisms, SNPs) on 'chips' that do multiple tests in a single assay (Meuwissen *et al.* 2001; Seidel 2010). The number of tests available for cattle ranges from a single SNP to over 700 000. Part of the current strategy is to obtain genome sequence on influential sires (Hayes *et al.* 2013). The technology for genome sequencing is improving all the time and it is likely to replace SNP chips in the future.

DNA testing is used for genotyping of major genes, pedigree verification and genomic selection, with many more SNPs genotyped respectively. If the causal mutation is known, then SNP genotyping can be very specific. Examples include variants in the myostatin (MSTN) gene affecting muscling or meat yield and in genes affecting tenderness (CAPN and CAST). The two variants in MSTN commonly tested for are F94L (common in Limousin) and 821dell11 (common in Belgian Blue) (Grobet *et al.* 1997). Myostatin is a negative regulator of muscle cell proliferation, so defects in the gene lead to less regulation or increased muscle mass (Sellick *et al.* 2007). F94L is a single SNP resulting in a single amino acid change from phenylalanine (F) to leucine (L) at position 94. It affects protein structure and therefore muscle activity. However, 821del11 is an 11 base pair deletion at position 821 and has a severe effect on myostatin activity (O'Rourke *et al.* 2012). F94L is currently used by Limousin breeders who have cattle graded up from other breeds to ensure they are homozygous. 821del11 is most commonly tested to identify carriers since homozygotes generally have an extreme phenotype. Whether desirable bulls are carriers or not depends on the objective of a specific breeding program. Both variants have been identified in other breeds where there has been selection pressure for muscling at some stage.

Tenderness of beef is affected by genetic variants in the calpain (enzyme) and calpastatin (calpain inhibitor) genes. The frequency of the 'tough' forms (alleles) of the gene is greater in *Bos indicus* breeds (White *et al.* 2005), but also varies in *Bos taurus* (Morris *et al.* 2006). Given that it is impossible to get information on this trait in young bulls, this genotype currently provides the only information for a tenderness EBV.

Horns in cattle present a risk to operators and lead to increased bruising in slaughter stock. Thus, dehorning is common practice in the cattle industry. In southern Australia where taurine breeds predominate, poll (absence of horns) is dominant so carriers (one copy of the favourable allele) are also polled. The only good reason for horned bulls to be used is if they are crossed to polled cows for a specific purpose or if they are a breed with unique characteristics, such as the Wagyu. In northern Australia, with many Zebu derived cattle, unfortunately the inheritance of poll is not so simple. If it is a single gene, heterozygotes have variable expression including poll, scurs and horned. Furthermore, the frequency of the poll gene in Zebu cattle is lower than desirable. Since the trait is so valuable, identification of carriers is important. Tests have been developed in Europe, the USA and Australia (Georges *et al.* 1993; Brenneman *et al.* 1996; Mariasegaram *et al.* 2012) but none has identified the causal mutation; the tests are not 100% accurate but are still valuable and utilised. If there are other genes involved then developing a test becomes even more difficult, so banning the use of genetically horned bulls is not yet a viable option.

Large use of AI in the Angus breed has led to proliferation of some genetic disorders. This is not an Angus issue, but would occur in any breed with a large amount of AI. That said, the recent experience with arthrogryposis multiplex (AM) is an interesting case study. An American bull called GAR Precision 1680, born in 1990, had high EBVs for carcass weight, eye muscle area (EMA) and intramuscular fat (IMF) which is a rare, but not impossible combination, as they are not correlated (Meyer 2005). Precision had a son born in 1995, CA Future Direction 5321, which was a trait leader for both EMA and IMF. He was widely used in the USA and Australia and has over 10 000 Breedplan recorded progeny in Australia. It would be rare for progeny to be mated with each other, but in the mid 2000s grand progeny of Future Direction were being mated, as many leading Angus cattle for EMA and IMF were related to Future Direction. When descendants were mated, some offspring were born dead with curly calf syndrome (AM). The genetic defect is autosomal recessive: as soon as an affected calf is born, it is clear that both parents are carriers. As genomic tools were available, pedigrees were well–recorded and affected calves were being identified, a research project to develop a DNA test for the gene was developed at the University of Illinois in collaboration with the American Angus Association (Beever and Marron 2009).

The work began in 2008, the mutation was identified and 700 AI sires were genotyped in just two months, which was an incredibly fast. The work identified that CA Future Direction was a carrier and he inherited the mutation from his father, GAR Precision. Rather than cull all suspected individuals, Angus breeders have been able to identify carriers and manage the defect by still selecting for the favourable genes in Future Direction descendents but ensuring that carrier bulls are not used, at least not in studs. Not all animals have to be genotyped, because if parents have been tested free, then the probability of progeny being carriers is known to be zero. AM carrier probabilities are now reported as part of Breedplan.

EBVs are more accurate when combining performance information on relatives. Thus, the accuracy of pedigree information is important. Even breeds and breeders who do not use EBVs in selection programs place great importance on accurate pedigree records. The cost of obtaining pedigree by mothering up calves and single–sire mating is significant. DNA tests are likely to become more cost–effective. DNA tests for parentage verification changed in 2012 from a minimum of nine highly variable microsatellite markers (recommend 12–14) approved by the International Society of Animal Genetics (ISAG), to SNP–based tests which are based on at least 96 markers (ISAG 2012). While SNPs are less variable between animals, this change was made because they are cheaper to genotype than microsatellite markers and are just as effective if sufficient numbers are used. An advantage of SNP–based tests is that if causal mutations for genetic diseases are identified, they can be included in the tests rather than relying on close linkage.

Rather than just determining parentage, SNP markers also offer the opportunity to completely reconstruct the relationship matrix. This has the advantage of being able to more closely describe relationships, e.g. the average relationship between animals with a common grandparent is $1/2^4 = 0.0625$ but this can vary significantly depending on the specific chromosomal segments inherited. This use of SNP markers requires a few thousand markers (Hayes and Goddard 2008; Harrison *et al.* 2012). Another use of SNP genotyping is developing relationships for animals with no history of pedigree recording but with relationships to currently recorded animals. This is useful for deciding which animals can be upgraded from commercial to stud status by breed societies.

The current 'paradigm shifter' in genetic evaluation is genomic selection (Meuwissen *et al.* 2001) because it can be used on animals without pedigree or performance data. It works by predicting genetic merit based on the genotyping of many (>50 000) SNPs and so can be conducted whenever it is convenient to collect a DNA sample. It doesn't require single–sire joining, mothering up at birth or maintenance of management groups. It has become common practice in the dairy industry where predictions are sufficiently accurate that they have replaced the need for progeny testing (Hayes *et al.* 2013). Not needing progeny testing has doubled genetic progress by halving the generation interval (Hayes *et al.* 2009). There are four reasons why genomic selection was developed first in dairy cattle: 1) selection is primarily for milk traits that cannot be measured in bulls, 2) there are already large numbers of accurate records, 3) there is one major breed and 4) records are likely to continue to be recorded for management purposes so tests can be updated almost automatically.

While genomic selection will work in beef cattle, it is still developing because of the large number of breeds and the requirements for extremely large numbers of accurate records. Some traits are relatively easy to measure (e.g. meat production) and so gains from genomic selection are significant, but smaller than for traits that are more difficult to measure (e.g. steer beef eating quality and heifer conception rate) and are likely to have no direct records (accuracy likely <0.1, Fig. 17.10), especially on young bulls. Unfortunately, by definition, traits that are difficult to measure lack large numbers of records for ongoing development of genomic tools. Pooling information across breeds and countries is a key strategy in developing these tests. The strategy on farm is likely to be two–stage selection where, once the best 10–25% of young bulls are identified, genomic testing could be conducted to narrow that to the 5% actually used in the stud. Alternatively, all young bulls that may be in a sale could be genotyped to aid purchasing decisions. Another sensible strategy is to genotype potential MOET donors to ensure investment in and multiplication of elite females. If there are disease issues that become an important part of the breeding objective but require exposure to the disease which affects production, genomic selection could be of enormous value.

Maintenance of management groups

In addition to accurate pedigree, genetic evaluation requires accurate measurements of traits (the selection criteria). These measurements are effectively used to rank animals within the same cohort or management group. For Breedplan, being in the same management group means they were bred in the same herd, are of same sex, same birth number (e.g. singles), same birth status (ET versus natural), born within 45 days (for birth and 200 day weight) or 60 days (for 400 and 600 day weight) of each other, have been weighed on the same day and run under the same conditions (Graser *et al.* 2005). Clearly, individual animals that have been separately fed cannot be compared to their paddock–raised contemporaries. Given that measurements are used to rank animals, the more animals in the group the more effective the comparisons. For example, the best one out of two is less effective (0.5) than the best one out of 10 (0.9). Effectiveness could be calculated as *(n–1)/n* where *n* is the number of cattle in the management group (Fig. 17.11). While small breeders struggle to have sufficient numbers for genetic evaluation, it is worth working hard to maintain group size by having fewer groups, as even small groups add information to genetic evaluation programs. Another factor that follows from the need to 'rank' animals is that if all animals have the same score (e.g. calving ease or cow body condition score), then the information is of no value for genetic evaluation (Graser *et al.* 2005) so scores need sufficient categories to separate animals.

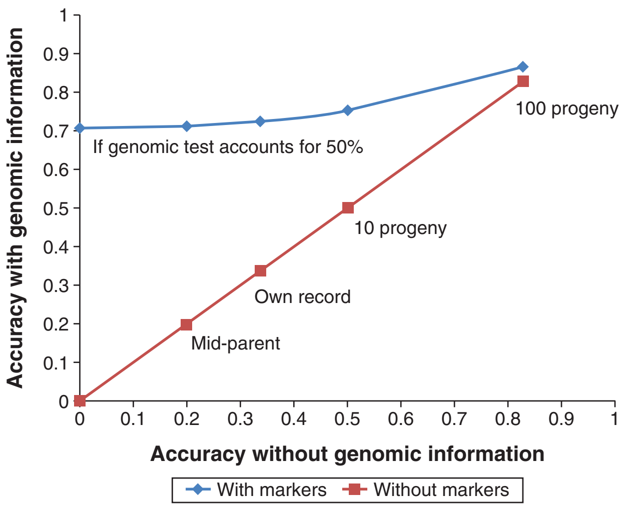


Figure 17.10: Value of genomic information when selecting a low–heritability trait if the genomic test accounts for 50% of the genetic variance (Accuracy 0.7). Current tests are <0.7.

Mate allocation

The greatest genetic progress happens by mating cattle with the highest EBVs. However, by definition, those with the highest EBVs are likely to be related to each other. Potential progeny may become too extreme in a specific trait despite having high index values. Thus, there is a need to balance the genetic progress by mating best to best, and at the same time minimising inbreeding to avoid genetic defects and ensure sufficient genetic variation to maximise long–term genetic progress. An optimisation

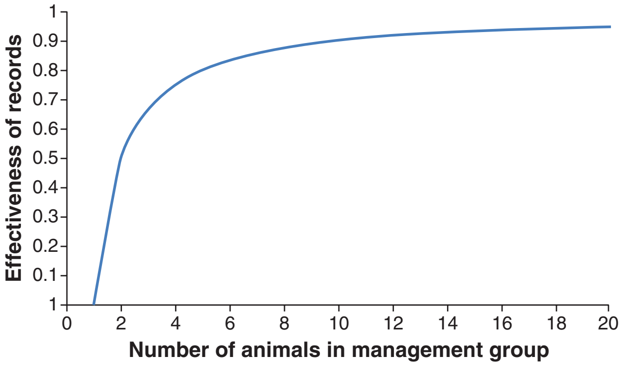


Figure 17.11: Importance of maintaining numbers in management groups.

tool has been developed to match sires and dams (Kinghorn 2011) and has been commercialised as 'MateSel'. It can be used to guide investment decisions on the numbers of donors to be flushed in MOET programs.

FUTURE DIRECTIONS

The most obvious way that breeding will change in the foreseeable future is through increased utilisation of genomic selection. This requires ongoing work to increase and maintain accuracy of prediction. The technology is at a challenging point: increased utilisation will lead to reduced cost and improved systems of capturing data, but utilisation is currently limited by cost and data systems. The other challenge for breeders with outstanding performance–recording systems is whether genomic testing is a threat or an opportunity, given that they are the ones providing the information for the tests that may be available to all breeders. This is likely to lead to increased specialisation of roles in the breeding sector, including a clearer elite and multiplier seedstock sector. This specialisation should also facilitate ongoing investment in developing tools for selection of difficult–to–measure traits such as reproduction, feed efficiency and meat quality.

Implicit in the expected increased specialisation is the likely ongoing dominance of purebred (or composite) cattle over structured crossbreeding systems. While outside the scope of this chapter, it is worth concluding by making the point that breeding is much more than just increasing production. Defined breeds can also facilitate underpinning of branded beef products, which can increase profit above commodity trading.

REFERENCES

Armstrong DT, Helm P, Irvine B, Petersen BA, Stubbings RB, McLean D, Stevens G, Seamark RF (1992) Pregnancies and live birth from *in vitro* fertilization of calf oocytes collected by laparoscopic follicular aspiration. *Theriogenology* **38**, 667–678. doi:10.1016/0093–691X(92)90029–Q.

Barwick SA, Henzell AL (2005) Development successes and issues for the future in deriving and applying selection indexes for beef breeding. *Australian Journal of Experimental Agriculture* **45**, 923–933. doi:10.1071/EA05068.

Barwick SA, Tier B, Swan AA, Henzell AL (2012) Estimation of accuracies and expected genetic change from selection for selection indexes that use multiple–trait predictions of breeding values. *Journal of Animal Breeding and Genetics*10.1111/jbg.12011.

Beef CRC (2012) <http://www.beefcrc.com/documents/publications/beef–bulletin/BeefBulletin26–9–12.pdf>.

Beever JE, Marron BM (2009) Screening for *Arthrogryposis multiplex* in bovines. US Patent Application Publication US2011/0151440 A1.

Breedplan (2010) *Interpreting Australian Angus Selection Indexes*. <http://breedplan.une.edu.au/index.php?option=com_content&task=view&id=14&Itemid=35>. Accessed 24 October 2012.

Breedplan (2011) *Interpreting Australian Brahman Selection Indexes*. <http://breedplan.une.edu.au/index.php?option=com_content&task=view&id=14&Itemid=35>. Accessed 24 October 2012.

Breedplan (2012a) *Understanding Trial Structural Soundness EBVs*. <http://breedplan.une.edu.au/index.php?option=com_content&task=view&id=14&Itemid=35>. Accessed 12 October 2012.

Breedplan (2012b) *Angus Animal Details*. <http://abri.une.edu.au/online/cgi–bin/i4.dll?1=22342A3D&2=232F5F&3=56&5=2B3C2B3C3A&6=5D5A5A5922272F212D&9=5A525B5C>. Accessed 12 October 2012.

Brenneman RA, Davis SK, Sanders JO, Burns BM, Wheeler TC, Turner JW, Taylor JF (1996) The polled locus maps to BTA1 in a *Bos indicus* x *Bos taurus* cross. *Journal of Heredity* **87**, 156–161. doi:10.1093/oxfordjournals.jhered.a022975.

Burrow HM, Siefert GW, Corbett NJ (1988) A new technique for measuring temperament in cattle. *Animal Production in Australia* **17**, 154–157.

Chenoweth PJ, Hopkins FM, Spitzer JC, Larson RE (2010) Guidelines for using the bull breeding soundness evaluation form. *Clinical Theriogenology* **2**, 43–50.

Coota Park (2012) <www.bluee.net.au>. Accessed 15 September 2012.

Cottle DJ, Romero C (2013) Improving pasture intake predictions by variable weighting of plant marker concentrations. Animal Science Feed Technology (submitted).

Cundiff LV, Gregory KE, Koch RM (1974a) Effects of heterosis on reproduction in Hereford, Angus and Shorthorn cattle. *Journal of Animal Science* **38**, 711–727.

Cundiff LV, Gregory KE, Schwulst FJ, Koch RM (1974b) Effects of heterosis on maternal performance and milk production in Hereford, Angus and Shorthorn cattle. *Journal of Animal Science* **38**, 728–745.

Cundiff LV, Szabo F, Gregory KE, Koch RM, Dikeman ME, Crouse JD (1993) Breed comparisons in the Germplasm Evaluation Program at MARC. In *Proceedings of Beef Improvement Federation Annual Symposium and Annual Meeting*. Asheville, NC, pp. 124–136.

Cundiff LV, Gregory KE, Van Vleck LD, Wheeler TL, Shackelford SD, Koohmaraie M, Thallman RM (2001). Preliminary results from cycle VI of the cattle germplasm evaluation program at the Roman L. Hruska US Meat Animal Research Center. Progress Report No. 20, pp. 1–13.

Cundiff LV, Wheeler TL, Gregory KE, Shackelford SD, Koohmaraie M, Thallman RM, Snowder GD, Van Vleck LD (2004) Preliminary results from cycle VII of the cattle germplasm evaluation program at the Roman L. Hruska US Meat Animal Research Centre. Germplasm Evaluation Program Progress Report No. 22, pp. 2–16.

Cuthbertson AZ, Deland MPB, Siebert BD (1990) The production efficiency of cattle of different breed and mature liveweight. *Proceedings of the Australian Society of Animal Production* **18**, 467.

Dickerson GE (1969) Experimental approaches in utilizing breed resources. *Animal Breeding Abstracts* **37**, 191–202.

Dickerson GE (1973) Inbreeding and heterosis in animals. In *Proceedings of the Animal Breeding and Genetics Symposium in Honor of Dr Jay L. Lush*. ASAS, Champaign, IL, pp. 54–77.

Ellis GF Jr, Cartwright TC, Kruse WE (1967) Heterosis for birth weight in Brahman Hereford crosses. *Journal of Animal Science* **24**, 93–96.

Exton S (2001) *Testing Beef Cattle for Net Feed Efficiency: Standards Manual*. <http://www.dpi.nsw.gov.au/agriculture/livestock/beef/breeding/general/feed–efficiency>.

Fitzhugh HA, Long CR, Cartwright TC (1975) Systems analysis of sources of genetic and environmental variation in efficiency of beef production: heterosis and complementarity. *Journal of Animal Science* **40**, 421–432.

Georges M, Drinkwater R, King T, Mishra A, Moore SS, Nielson D, Sargeant LS, Sorrenson A, Steele MR, Zhao X, Womack JE, Hetzel DJS (1993) Microsatellite mapping of a gene affecting horn development in *Bos taurus*. *Nature Genetics* **4**, 206–210. doi:10.1038/ng0693–206.

Goddard M (2009) Genomic selection: prediction of accuracy and maximization of long–term response. *Genetica* **136**, 245–257. doi:10.1007/s10709–008–9308–0.

Gordon IR (2003) *Laboratory Production of Cattle Embryos*. 2nd edn. CAB International, Wallingford, UK.

Graser H–U, Tier B, Johnston DJ, Barwick SA (2005) Genetic evaluation for the Australian beef industry. *Australian Journal of Experimental Agriculture* **45**, 913–921. doi:10.1071/EA05075.

Gregory KE, Cundiff LV (1980) Crossbreeding in beef cattle: evaluation of systems. *Journal of Animal Science* **51**, 1224–1242.

Gregory KE, Swiger LA, Koch RM, Gumption LJ, Rowden WW, Ingalls JE (1965) Heterosis in preweaning traits of beef cattle. *Journal of Animal Science* **24**, 21–28.

Grobet L, Royo Martin LJ, Poncelet D, Pirottin D, Brouwers B, Riquet J, Schoeberlein A, Dunner S, Menissier F, Massabanda J, Fries R, Hanset R, Georges M (1997) A deletion in the bovine myostatin gene causes the double–muscled phenotype in cattle. *Nature Genetics* **17**, 71–74. doi:10.1038/ng0997–71.

Growsafe (2012) <www.growsafe.com>. Accessed 15 September 2012.

Harrison BE, Bunch RJ, McCulloch R, Williams P, Sim W, Corbet NJ, Barendse W (2012) The structure of a cattle stud determined using a medium density single nucleotide polymorphism array. *Animal Production Science* **52**, 890–898. doi:10.1071/AN11267.

Hayes BJ, Goddard ME (2008) Technical note: prediction of breeding values using marker–derived relationship matrices. *Journal of Animal Science* **86**, 2089–2092. doi:10.2527/jas.2007–0733.

Hayes BJ, Miller SP (2000) Mate selection strategies to exploit across– and within–breed dominance variation. *Journal of Animal Breeding and Genetics* **117**, 347–359. doi:10.1046/j.1439–0388.2000.00252.x.

Hayes BJ, Bowman PJ, Chamberlain AJ, Goddard ME (2009) Invited review: genomic selection in dairy cattle: progress and challenges. *Journal of Dairy Science* **92**, 433–443. doi:10.3168/jds.2008–1646.

Hayes BJ, Lewin HA, Goddard ME (2013) The future of livestock breeding: genomic selection for efficiency, reduced methane emission intensity, and adaption. *Trends in Genetics* **29**, 206–214. doi:10.1016/j.tig.2012.11.009.

Hill WG (1974) Prediction and evaluation of response to selection with overlapping generations. *Animal Production* **18**, 117–139. doi:10.1017/S0003356100017372.

ISAG (2012) <http://www.isag.us/committees.asp>. Accessed 28 May 2013.

Jeyaruban G, Tier B, Johnston DJ, Graser H–U (2012) Genetic analysis of feet and leg traits of Australian Angus cattle using linear and threshold models. *Animal Production Science* **52**, 1–10. doi:10.1071/AN11153.

Johnston DJ, Graser H–U, Moore KL, Graham JF (2003) Breedplan multi–breed EBVs for growth traits in Angus, Hereford, Simmental and Limousin breeds. *Association for the Advancement of Animal Breeding and Genetics* **15**, 269–272.

Johnston DJ, Graser H–U, Tier B (2008) Research and development of trial Brahman Breedplan tenderness EBV. <agbu.une.edu.au/brahman%20tenderness%20EBVs.pdf>. Accessed 15 March 2013.

Johnston DJ, Tier B, Graser H–U (2012) Beef cattle breeding in Australia with genomics: opportunities and needs. *Animal Production Science* **52**, 100–106. doi:10.1071/AN11116.

Kinghorn BP (2011) An algorithm for efficient constrained mate selection. *Genetics, Selection, Evolution*. **43**, 4.http://www.gsejournal.org/content/43/1/4>10.1186/1297–9686–43–4.

Koch RM (1972) The role of maternal effects in animal breeding: VI. Maternal effects in beef cattle. *Journal of Animal Science* **35**, 1316–1323.

Lohuis MM, Smith C (1994) Risks associated with teams of bulls. *Proceedings of 5th World Congress on Genetics Applied to Livestock Production 18*, 298–301.

Long CR, Stewart TS, Cartwright TC, Jenkins TG (1979) Characterization of cattle of a five breed diallel: I. Measures of size, condition and growth in bulls. *Journal of Animal Science* **49**, 418–431.

MacNeil M, Dearborn DD, Cundiff LV, Dinkel CA, Gregory KE (1989) Effects of inbreeding and heterosis in Hereford females on fertility, calf survival and pre–weaning growth. *Journal of Animal Science* **67**, 895–901.

Mariasegaram M, Harrison BE, Bolton JA, Tier B, Henshell JM, Barendse W, Prayaga KC (2012) Fine–mapping the POLL locus in Brahman cattle yields the diagnostic marker CSAFG29. *Animal Genetics* **43**, 683–688. doi:10.1111/j.1365–2052.2012.02336.x.

McDonald A (2006) *Scoring of Docility in Limousin Cattle*. <http://www.limousin.com.au/Scoring%20of%20Docility.html>. Accessed 15 March 2013.

Meuwissen THE, Hayes BJ, Goddard ME (2001) Prediction of total genetic value using genome wide dense marker maps. *Genetics* **157**, 1819–1829.

Meyer K (2005) Genetic principal components for live ultrasound scan traits of Angus cattle. *Animal Science* **81**, 337–345. doi:10.1079/ASC50850337.

MLA (2012a) *More Beef from Pastures Manual. Module 8. Meeting Market Specifications*.

MLA (2012b) *More Beef from Pastures Manual. Module 5. Cattle Genetics*.

Morris CA, Cullen NG, Packard PM (1985) Foot scores of cattle. 1. Variation among subjective scores of Angus cattle from different herds and sire groups. *New Zealand Journal of Experimental Agriculture* **13**, 235–240. doi:10.1080/03015521.1985.10426088.

Morris CA, Cullen NG, Hickey SM, Dobbie PM, Veenvielt BA, Manley TR, Pitchford WS, Kruk ZA, Bottema CDK, Wilson TW (2006) Genotypic effects of calpain 1 and calpastatin on the tenderness of cooked *M. longisimus dorsi* steaks from Jersey x Limousin, Angus and Hereford–cross cattle. *Animal Genetics* **37**, 411–414. doi:10.1111/j.1365–2052.2006.01483.x.

Newman S, Stewart TS, Goddard ME, Gregory M (1997) Hotcross: a decision support aid for crossbreeding of beef cattle in tropical and sub–tropical environments. *Association for the Advancement of Animal Breeding and Genetics* **12**, 400–403.

O'Rourke BA, Greenwood PL, Arthur PF, Goddard ME (2012) Inferring the recent ancestry of *myostatin* alleles affecting muscle mass in cattle. *Animal Genetics* **44**, 86–90. doi:10.1111/j.1365–2052.2012.02354.x.

Paterniani E, Lonnquist JH (1963) Heterosis in interracial crosses of corn (*Zea mays L.*) *Crop Science* **3**, 504–507. doi:10.2135/cropsci1963.0011183X000300060014x.

Pitchford WS, Barlow R, Hearnshaw H (1993) Growth and calving performance of cows from crosses between the Brahman and Hereford. *Livestock Production Science* **33**, 141–150. doi:10.1016/0301–6226(93)90245–D.

Pitchford WS, Deland MPB, Siebert BD, Malau–Aduli AEO, Bottema CDK (2002) Genetic variation in fatness and fatty acid composition of crossbred cattle. *Journal of Animal Science* **80**, 2825–2832.

Ponzoni RW, Newman S (1989) Developing breeding objectives for Australian beef cattle production. *Animal Production* **49**, 35–47. doi:10.1017/S0003356100004232.

Seidel GE Jr (2010) Brief introduction to whole–genome selection in cattle using single nucleotide polymorphisms. *Reproduction, Fertility and Development* **22**, 138–144. doi:10.1071/RD09220.

Sellick GS, Pitchford WS, Morris CA, Cullen NG, Crawford AM, Raadsma HW, Bottema CDK (2007) Effect of myostatin F94L on carcass yield in cattle. *Animal Genetics* **38**, 440–446. doi:10.1111/j.1365–2052.2007.01623.x.

Siebert BD, Deland MPD, Pitchford WS (1996) Breed differences in the fatty acid composition of subcutaneous and intramuscular lipid of early and late maturing, grain–finished cattle. *Australian Journal of Agricultural Research* **47**, 943–952. doi:10.1071/AR9960943.

Simm G (1998) *Genetic Improvement of Cattle and Sheep*. Farming Press, Miller Freeman UK.

Splan RK, Cundiff LV, Dikeman ME, Van Vleck LD (2002) Estimates of parameters between direct and maternal effects for weaning weight and direct genetic effects for carcass traits in crossbred cattle. *Journal of Animal Science* **80**, 3107–3111.

Wheeler TL, Cundiff LV, Shachelford SD, Koohmaraie M (2004) Characterization of biological types of cattle (Cycle VI): carcass, yield, and *longissimus* palatability traits. *Journal of Animal Science* **82**, 1177–1189.

White SN, Casas E, Wheeler TL, Shackelford SD, Koohmaraie M, Riley DG, Chase CCJrJohnson DD, Keele JW, Smith TPL (2005) A new single nucleotide polymorphism in CAPN1 extends the current tenderness marker test to include cattle of *Bos indicus, Bos taurus*, and crossbred descent. *Journal of Animal Science* **83**, 2001–2008.

Wiltbank JN, Gregory KE, Rothlisberger JA, Ingalls JE, Kasson CW (1967) Fertility of beef cows bred to produce straightbred and crossbred calves. *Journal of Animal Science* **26**, 1005–1010.

Xiang R, Ghanipoor–Samami M, Johns WH, Eindorf T, Rutley DL, Kruk ZA, Fitzsimmons CJ, Thomsen DA, Roberts CT, Burns BM, Anderson GI, Greenwood PL, Hiendleder S (2013) Maternal and paternal genomes differentially affect myofibre characteristics and muscle weights of bovine foetuses at mid–gestation. *PLoS ONE* **8**(1), e53402. doi:10.1371/journal.pone.0053402doi:10.1371/journal.pone.0053402.

18 Production efficiency

D.J. Cottle and W.S. Pitchford

IMPORTANCE AND MEASUREMENT

Livestock industries operate in an internationally competitive environment with changes in currency value and terms of trade affecting the competitiveness of industries in export-oriented countries. For example, Australia's share of the Japanese and South Korean beef markets has been under intense competition from the USA since 1986 (Bindon and Jones 2001; Chapters 4, 8, 11).

Beef market share is impacted by prices of other meats, animal protein substitutes and changing consumer preferences. Input costs for intensive beef producers increase with any expansion of the crop-based biofuel sector. Traceability, food safety and animal welfare concerns add costs to the industry without necessarily bringing greater returns. For example, if exporting South American countries are free of foot and mouth disease they can compete more for Australian beef markets in Canada and Taiwan.

These and other challenges are best met by production efficiency improvements to ensure the continuing economic viability of the beef industry. Increased productivity (a measure of the efficiency of the production process) reflects the ability to produce more goods and services (outputs) given available resources (inputs) (Chapter 20). Production efficiency gains are usually achieved through lowered costs and/or higher outputs, thus greater profit margins for the producer. Whether market or feed prices are high or low, production efficiency largely determines the magnitude of farm profit or loss (Chapter 20).

Production efficiency can be measured in individual animals, at individual farm level or at higher aggregated levels, e.g. regional, state or industry-wide. The focus of this chapter is on the mix of strategies available to increase production efficiency at the animal and farm level, but an overview of beef industry production efficiency follows. At the individual animal level, reproductive efficiency (the ability of cows to become pregnant and produce a live calf on an annual basis with maximum growth) and feed efficiency (the conversion of feed into energy used for maintenance, weight gain, milk production and reproduction) are critical factors in biological efficiency. Earlier chapters of this book cover the importance of managing the health (Chapter 13), reproduction (Chapter 14), stocking rate (Chapter 15), nutrition (Chapter 16) and breeding (Chapter 17) of cattle herds.

MEASUREMENT OF EFFICIENCY AT INDUSTRY LEVEL

The Australian Bureau of Agricultural and Resource Economics (ABARE) analyses overall productivity at aggregated levels in various industries, including the beef industry, by calculating total factor productivity (TFP, also known as multifactor productivity) by comparing a ratio of total outputs relative to total inputs used in the production of output (Nossal *et al*. 2008). When there is more than one input (or output) it is necessary to use prices to develop weights for aggregation. As the structure of inputs and outputs differ between farms, an indexing (Fisher) procedure is used to aggregate these diverse inputs (or outputs) into TFP indexes.

Nossal *et al.* (2008) calculated the geometric mean of the Laspeyres and Paasche indices (the Fisher index) of price and quantities of inputs and outputs between the current and base periods. The Laspeyres index, which only requires price data for the new period and uses the values estimated for the base period as its weights, tends to overstate inflation, while the Paasche index, which requires price and quantity data for the new period and uses the values for the current period as its weights, tends to understate it. The indices do not account for consumers typically reacting to price changes by changing the quantities purchased (IMF 2009). The Fisher index tries to overcome the problem of under- and overestimation of inflation, but there is no guarantee that the indices will exactly compensate for each other. Further information on this methodology can be found in Davidson *et al.* (2006).

Productivity measurement has been extended from the simple TFP index towards more refined decomposition methods (e.g. Ma *et al.* 2007). In the simpler framework, the growth rate of the index is usually interpreted as a measure of technical change, but this interpretation incorporates several restrictive assumptions, such as constant returns to scale and 100% allocative and technical efficiency. More recently, input distance functions have been used in attempts to overcome some of these shortcomings and to identify the components of productivity change (Coelli and Perelman 2000; Khumbakar and Lovell 2000; Karagiannis *et al.* 2004). This newer approach does not require any behavioural assumptions, such as cost minimisation or profit maximisation, to provide a valid representation of the underlying production technology (Brummer *et al.* 2002).

Despite the limitations, TFP is a useful, simple indicator for monitoring and analysing the performance of both farm businesses and industries (Nossal *et al.* 2008). Trends in TFP for the overall Australian beef industry for 1977–2006 are shown in Fig. 18.1. Annual output growth in the northern (1.3%) and southern regions (1.6%) were higher than northern (0.1%) and southern (0.2%) input growth, so TFP growth was +1.2% (northern) and +1.3% (southern) on average.

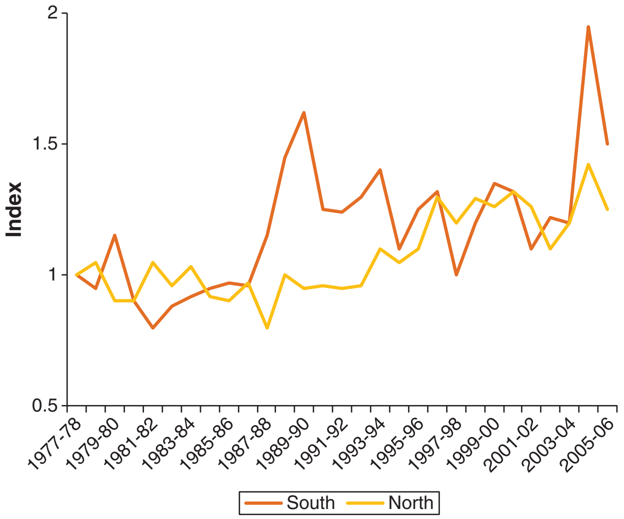


Figure 18.1: Growth in TFP in the Australian beef industry, 1977–2006. The northern region is defined as the Northern Territory, Queensland and northern pastoral zone of Western Australia. Source: Nossal *et al.* (2008).

The most widely accepted concept of economic efficiency was developed by Vilfredo Pareto, an Italian economist. Given an initial allocation of goods among a set of individuals, a change to a different allocation that makes at least one individual better off without making others worse off is called a Pareto improvement. An allocation is defined as efficient or optimal when no further improvements can be made. A production-possibility frontier (PPF) curve is a simple example that illustrates Pareto efficiency within the achievable limits of current production capacity.

In Fig. 18.2, all points on the PPF curve are at maximum productive efficiency (i.e. no more output can be achieved from the given inputs). All points inside the frontier (e.g. U) can be produced but are productively inefficient and all points outside the curve (e.g. O) cannot be produced with the given, existing resources (Standish 2000). A move from U to D results in some people being better off without making any others worse off (a Pareto improvement). However, moving from point U to points outside the EDF arc on the PPF curve (e.g. points B and C), is not a Pareto improvement. The EDF arc is Pareto efficient within the achievable limits of current production capacity.

A point on the PPF curve satisfies allocative efficiency if, for given preferences and distribution of income, no movement along the curve or redistribution of income could raise the satisfaction or utility of someone without lowering the utility of someone else (Samuelson and Nordhaus 2004). Koopmans (1951) extended the notion of Pareto efficiency to production economics. A producer was considered most technically efficient if an increase in any output required a reduction in at least one other

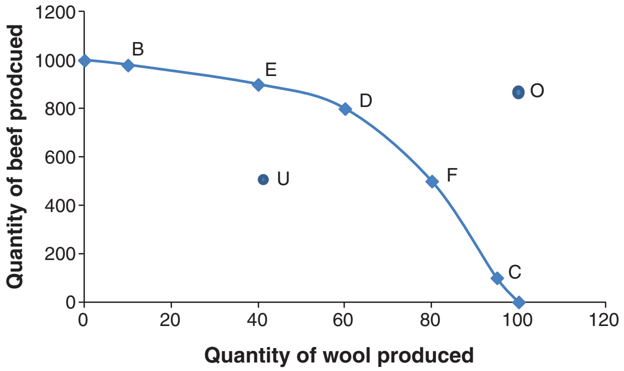


Figure 18.2: The PPF curve for producing beef and wool. The curve denotes maximum possible production. Point O lies outside the curve, representing an impossible output for existing capital and/or technology.

output or an increase in at least one input, and if a reduction in any input required an increase in at least one other input or a reduction in at least one output. This concept can be applied at various levels of aggregation of outputs, e.g. from a farm to the whole beef industry.

The empirical (information gained by means of observation or experiments) production efficiency literature focuses on measuring levels of technical and allocative efficiency and identifying potential sources/causes of inefficiency. Economic efficiency is the multiple of these two efficiencies. Allocative efficiency reflects the ability of the farm to use the inputs in optimum proportions given their respective prices and the production technology. Technical efficiency is the measure of the farm's success in producing maximum output from a given set of inputs. Alternatively, it is the ability to operate on the production frontier. Economic efficiency is defined as the capacity of a farm to produce a predetermined quantity of output at minimum cost for a given level of technology. The dairy sector (Richards and Jeffrey 2000; Mbaga *et al.* 2003; Hailu *et al.* 2005) has been the most studied in the livestock literature. Most efficiency analyses have focused on the measurement of technical efficiency (Bravo-Ureta *et al.* 2007). For example, Iraizoz *et al.* (2005) and Trestini (2006) respectively examined Spanish and Italian beef farms and identified significant departures from the (efficient) PPF curve. Only a few studies have estimated technical, allocative and economic efficiencies (Bravo-Ureta and Evenson 1994; Featherstone *et al.* 1997; Samarajeewa *et al.* 2012; Mlote *et al.* 2013).

Samarajeewa *et al.* (2012) estimated the production efficiency and sources of efficiency variation for Canadian beef producers in Alberta. They also compared results from different density functions and truncation points for the error term in their stochastic frontier models (Greene 1980). The Cobb–Douglas function ($Q = AL^{\alpha}K^{\beta}$) (Murillo-Zamorano 2004) was used to represent the cow–calf production function to derive the stochastic cost frontier in order to calculate relative economic and allocative efficiencies. The production function and the inefficiency effects models were estimated simultaneously in one stage (Coelli 1995):

$$\ln y_{it} = \beta_0 + \Sigma_{k=1}^{6}\, \hat{a}_k \ln x_{kit} + \Sigma_{j=1}^{7} \hat{a}_j\, D_{ijt} + \mathring{a}_{it}$$

where:

y_{it} = output per cow (real value of weaned calves);

x = vector of inputs (labour, capital, winter feed and pasture, veterinary, medicine and breeding expenses and all other expenses, i.e. fuel, machinery, repairs and maintenance, interest, tax, water, insurance etc.);

k indexes the inputs per cow for the ith farm in year t;

β = parameters to be estimated;

D_{ijt} = the year dummy variables (e.g. weather, technology, policy) for the period studied;

$\varepsilon = v - u$, where v captures random effects and u, a one-sided error term, captures technical inefficiency;

$\varepsilon_{\mathrm{it}} = v_{\mathrm{it}} - u_{\mathrm{it}}$ = composed error term.

The stochastic cost frontier was calculated as:

$\ln \mathrm{c}_{it} = \acute{a}_0 + \acute{a}_1 \ln \mathrm{y}^{*}_{it} + \Sigma_{k=2}^{6}\, \acute{a}_k \ln W_{kit} + \Sigma_{j=1}^{7}\, \acute{a}_j\, D_{ijt}$

where:

c_{it} = cost of production;

y^{*}_{it} = frontier output adjusted for technical efficiency and stochastic error;

k indexes the inputs per cow for the i^{th} farm in year t;

w_{kit} = input prices;

$\acute{a}_j$ = derived analytically from the estimated production function;

D_{ijt} = the year dummy variables.

The technical inefficiency effects model used was:

$u_{it} = \mathrm{g}(\mathrm{z}_{it};\, \mathrm{d}) + \grave{\mathrm{u}}_{it}$

where:

z_{it} = vector of environmental and management factors, e.g. farm location, herd size, government support, conception rate, weaning rate, calving rate, share of family labour, bedding cost, marketing costs, etc. that explain production efficiency across farms;

$\grave{\mathrm{u}}_{it}$ = random variable, defined by the truncation below of the normal distribution:

$$u_{it} = \mathrm{g}(\mathrm{z}_{it};\, \mathrm{d}) + \grave{\mathrm{u}}_{it} \geq 0 \text{ such that } \grave{\mathrm{u}}_{it} \geq -\, \mathrm{g}(\mathrm{z}_{it};\, \mathrm{d}).$$

Average technical, allocative and economic efficiencies were calculated as 83% (±13%), 78% (±20%) and 67% (±22%) respectively, suggesting a significant departure from the stochastic production frontier and a large range of efficiencies in the 333 beef farms studied. Thus farms were not fully successful in achieving either maximum possible output from given inputs, technology and year conditions, or optimally allocating existing resources at the given input prices. Allocative inefficiency contributed more to economic inefficiency than technical inefficiency with an opportunity, on average, to produce the same level of output with 33% less production cost. Biological efficiency (e.g. increased conception, calving and weaning rates) was the most influential factor affecting production (technical) efficiency of the cow–calf operation, as earlier suggested by Mathis and Sawyer (2000), and it may be improved by better decision-making in the selection of breeds and feed. In their study, larger herd size, higher share of family labour and greater expense for bedding material also increased efficiency.

An analysis of broadacre farms in Australia found that improving productivity in smaller farms depended more on the ability to access advanced technologies than on their ability to simply expand in size and benefit from returns to scale (Sheng *et al*. 2011). Samarajeewa *et al*. (2012) also noted that some smaller beef producers in Canada had higher levels of production efficiency than large producers, so herd size was not the only driving force behind efficiency. Efficiency was also related to receipt of less government subsidies, which appeared to distort resource allocations.

The stochastic production frontier approach was also used by Villano *et al*. (2009) to study a sample of beef farms with 227 observations in south-west Victoria from 1995–2005. Technically inefficient farms did not increase in productivity, measured as TFP, whereas best-practice producers made modest gains.

MEASUREMENT OF EFFICIENCY ON FARM

Measuring efficiency can be as simple as calculating a ratio of outputs to inputs. However, the choice of which inputs and outputs to use on a farm (Fig. 18.3) and how to value them can be challenging. Farm/herd production efficiency is influenced by feed use efficiency, feeding practices, stocking rates, herd health status, culling rates, reproductive efficiency, management restrictions, breeding and genetics. These factors, other than feed use efficiency, are covered in detail in other chapters.

Calculation of the relative production efficiency on a beef farm can be done by a comparative analysis of selected inputs and outputs, with other herds used as benchmarks. These studies are more valid if the farms have similar resources and producer goals (Chapter 20). In the USA, the National Integrated Resource Management Standardized Performance Analysis (IRM-SPA) Guideline (USDA 1992) has been used for this purpose. For example, Dunn (2000) analysed 148 herds from eight northern plains states from 1991–99; Falconer *et al*. (1999) reported on 187 Texan herds from 1992–98, Miller *et al*. (2001) studied 225 Illinois and Iowa herds from 1996–99, Ramsey *et al*. (2005) presented the results from 394 herds from the southern plains states of Oklahoma, Texas and New Mexico from 1991–2001, while Cho *et al*. (2011) analysed 104 SPA beef cow herds from the same states from 2004–08, using a log-linear stochastic frontier production model, similar to Samarajeewa *et al*. (2012). While Ramsey *et al*. (2005) considered management factors as directly affecting farm output, Cho *et al*. included additional labour data to take into account labour variations in the SPA data, and used dummy variables for years and rainfall data to take into account weather and other environmental variations in the SPA data.

Dunn (2002) noted that an understanding of how SPA measurements are calculated is critical for their correct

Figure 18.3: Inputs and outputs that may be included when measuring production efficiency in beef cattle. Source: Adapted from Ostergaard *et al*. (1990).

use and application by management. Net income, by definition, is not a measurement of managerial efficiency. Return on assets, calculated on a financial basis with accrual adjustments and using pre-tax net income, is a better measure of profit and managerial efficiency (Chapter 20).

Miller *et al*. (2001) defined financial costs as cash-flow costs and included debt servicing and hired labour; economic costs reflect the opportunity cost of inputs and include a charge for invested capital (rather than principal and interest payments) and the value of family and operator labour. Each observation was analysed as the difference from the mean for that given year, to eliminate environmental and cattle cycle effects. The dependent variable (indicator of profit) was return to labour and management per cow (RLM). Independent variables were feed, operating, depreciation, capital, hired labour costs, calf weight, calf price, cull weight, cull price, weaning percentage, calving distribution, herd size, and investment. A financial prediction equation using eight variables accounted for 82% of the variation among farms. For both economic and financial analyses, feed cost was the most critical control point, accounting for over 50% of the variation in profit between these US herds. In the financial regression model, depreciation cost was the second critical factor, accounting for 9% of variation in RLM, followed by operating cost (5%) and calf weight (5%). The other variables were capital charge, calf price, weaning percent and herd size. Cost factors accounted for more variation in RLM than production, reproduction or producer-controlled marketing factors. The large herd-to-herd variation seen for many cost factors indicated that many producers can improve their profitability by finding ways to lower production costs while maintaining production.

Benchmarks and key performance indicators

Care is needed when developing benchmarks for biological or financial performance (Chapter 20; Dunn 2002). In Australia, consultancy firms often provide productivity benchmarking analyses. Farms are ranked on standard benchmarks which form the basis on which potential improvements to the business are identified. For example, Sackett and McEachern (2003) provided a case study of a beef farm that had consistently ranked in the top 20% of its southern (winter rainfall) clients for herd profitability measured by profit and kg beef produced per ha (rather than return on assets). Lower costs of production ($/kg beef), higher mid-winter stocking rates (dry sheep equivalents (DSE)/ha/100 mm) due to pasture improvement and fertiliser use, lower supplementary feed ($/DSE) and higher labour productivity (DSE/labour unit) were given as the most significant factors affecting profit margin. Stocking rate units related to rainfall should only be used to compare farms in regions or zones with similar seasonal rainfalls.

The inputs and outputs recorded differ between consultants but often key beef performance indicators include cost of production, price received/kg beef, gross $/head sold, kg beef/ha, kg beef/ha/100 mm rainfall, mid-winter stocking rate (DSE/ha), percent potential stocking rate, kg beef/DSE, kg beef /head sold, DSE/labour unit and average annual DSE carried.

Profit Probe software (RCS 2013) is used by Resource Consulting Services (RCS) to calculate key performance indicators (KPIs) for profitability (economics), productivity, people, pecuniary (finance) and property indicators; beef farms are ranked within benchmark groups and benchmark KPI values are given. The people KPIs include gross product ($/full-time equivalents, FTE), stock managed (DSE/FTE), farm area (ha/FTE), training (days/FTE) and holidays (days/FTE). Interestingly, RCS advises its clients to aim to have fewer holidays than the benchmark value. Other consultants place more emphasis on recreation and activities that some may regard as trivial, such as cleaning out sheds on at least an annual basis.

Wilson *et al*. (2004) reviewed whole farm performance indicators and benchmark practices used in eastern Australia and found most consultants utilised a measure of profitability as the key whole farm performance indicator. This generally related to the net profit earned by the business and, as such, identified the net income available to satisfy living expenses, taxation requirements, capital repayments and facilitate future investment opportunities. Not all consultants incorporated non-farm income or an allowance for a manager's wage in their measurement of net profit. The exclusion of non-farm income can enable a better analysis of farm performance, especially the longer-term sustainability and resource use of the farm system.

Wilson *et al*. (2004) found common performance indicators tend to focus on measures associated with:

1. physical scale and performance (e.g. total areas, grazed area, cropped area, improved pasture area, stocking rate and rainfall), with indexes that clearly focused on the production system but that may not provide much information on the longer-term farm sustainability;

2. profitability (e.g. farm input costs as percent of income, debt servicing costs as a percent of farm income, net income per 100 mm of rainfall, net income per hectare, net income per labour unit, and return to capital (total assets) with measures that have proliferated without clear guidelines on which are more critical for assessing farm performance;
3. solvency (e.g. total land value, land value per family, total assets, total assets per family, equity as a percent of total assets, and debt as a percent of total assets).

Wilson *et al*. (2004) found that few consultants focused on performance indicators related to the ability to meet short-term financial commitments (liquidity).

Henning *et al*. (2011) used the financial ratios used by the US Farm Financial Standards Council (FFSC 2008) as a benchmarking system for farmers in the Northern Cape of South Africa, divided into mixed, cropping and livestock enterprises. The border ratios between high-, middle- and low-performing farms were very different between farm types. The FFSC proposed that data from financial statements, the income statement and balance sheet contain enough information to analyse the financial position of a farm using standardised processes, according to 16 financial (Sweet 16) ratios (Hoag 2009). The ratios are divided into five categories: liquidity, solvency, profitability, repayment capacity and financial efficiency (Table 18.1).

Wilson *et al*. (2004) argued that there was a need for a more consistent approach in deriving Australian performance indexes (e.g. is operator wage or non-farm income included?). They found that most indexes in 2004 were focused on the financial performance of farm businesses and enterprises and the underlying biophysical production system. Few attempted to measure the longer-term sustainability in terms of economics, ecological, environmental and social components, nor how those categories were integrated (Chapter 19). This more holistic approach has slowly started to develop. For example, Vanguard Business Services, Dubbo, NSW, provides both financial indicators (benchmarks) and 'On Track' paddock indicators for 31 criteria that measure land and soil health. However, indicators are of limited value if they cannot be acted upon.

STRATEGIES TO MAXIMISE PRODUCTION EFFICIENCY

Benchmarking, if used in context, may provide some guidance about a farm's relative performance and the areas that most need attention. However, with or without available comparative performance data, typical priorities exist for improving production efficiency. Table 18.2 lists the key factors in maximising production efficiency given by McCosker (2011). T. McCosker (pers. comm.) suggested that the three main keys to profitability are 1) increasing turnover, 2) increasing gross margin and 3) reducing overheads.

The six grazing management principles referred to in Table 18.2, in priority order, are:

1. ensure that plants have adequate rest;
2. match stocking rate to carrying capacity;
3. plan, monitor and manage grazing;
4. manage livestock effectively (i.e. nutrition, health, reproduction, water quality and quantity, distance walked to feed, stress and grazing management influences);
5. use maximum stock density for minimum time;
6. manage for biodiversity.

The eight reproduction principles (Table 18.2) are:

1. keep cows at a body condition score of 3+;
2. 60-day calving period (less for first calvers);
3. well-grown replacement heifers;
4. cows on a rising plane of nutrition before mating;
5. fertility-tested bulls;
6. 48 hour calf removal at least five weeks after bull removal to remove the nursing stimulus and shorten post-partum anoestrus (not always effective, see Chapter 14);
7. sound genetic selection and monitoring;
8. mating timed correctly (matching quantity and quality of feed supply to biological demand).

Holmes (2010) noted that the more profitable businesses within southern beef herds had a superior combination of 1) higher productivity (kg beef/ha) through more efficient use of resources, such as land and pasture, and 2) lower cost of production (produce each kilogram cheaper), by diluting their overhead cost structure. The combination of achieving these two goals, without any significant loss in average price received, collectively contributed to superior returns. Holmes (2010) gave a priority order for improving productivity (Fig. 18.4) and considered stocking rate and average sale weight the most important factors influencing per hectare production of beef. Improved genetics includes feed use and reproductive efficiency, which are a major focus of this chapter. The greater importance of per hectare production than

Table 18.1: Suggested guidelines for (Sweet 16) farm financial ratios with high-, middle- and low-performing values

	Performance level				
Ratio	**Low**	**Border**	**Middle**	**Border**	**High**
Liquidity					
Total current farm assets:total current farm liabilities (current ratio)		≥1.0		≥2.0	
Total current farm assets:total current farm liabilities (working capital)		$ ∝ farm size		$ ∝ farm size	
Solvency					
Total farm liabilities:total farm assets (debt:asset ratio)		≥60%		≥30%	
Total farm equity:total farm assets (equity:asset ratio)		≤40%		≥70%	
Total farm liabilities:total farm equity (debt:equity ratio)		≥150%		≥43%	
Profitability					
Matching revenues with expenses incurred to create revenue, plus gain or loss on the sale of business assets before taxes (net farm income, accrual adjusted)		$ ∝ farm size		$ ∝ farm size	
Net farm income from operations – owner withdrawals for unpaid labour and management:average total farm assets (rate of return on assets)		≤1%		≥5%	
Net farm income from operations – owner withdrawals for unpaid labour and management):average total farm equity (rate of return on equity)		≤5%		≥10%	
Net farm income from operations + farm interest expense – owner withdrawals for unpaid labour and management:gross revenues (operating profit margin)		≤20%		≥35	
Repayment capacity					
Funds available for payments as a percentage of the principal and interest payments (term debt ratio)		≤110%		≥135%	
Funds available for payments – principal and interest payments (capital replacement margin)		$ ∝ farm size		$ ∝ farm size	
Financial efficiency					
Gross revenues:average total farm assets (asset turnover ratio)		≤20%		≥40%	
Total operating expenses – depreciation/amortisation expense:gross revenues (operating expense ratio)		≥80%		≤60%	
Depreciation/amortisation expense:gross revenues (depreciation expense ratio)		≥20%		≤10%	
Total farm interest expense:gross revenues (interest expense ratio)		≥20%		≤10%	
Net farm income from operations:gross revenues (net income ratio)		≤10%		≥20%	

Middle performance is between the low and high border ratio values.
Source: Adapted from Blocker *et al.* (2003); FFSC (2008).

per head production and the impact on profitability of stocking rate are covered in Chapter 15.

Strategies and management tools to achieve production efficiency are also covered in Meat and Livestock Australia (MLA)'s More Beef from Pastures program. The manual's first module presents an enterprise profitability tree (Fig. 18.5) that outlines the key areas of the production system that have a major impact on the profitability of a beef enterprise from a critical control point perspective. By identifying each factor that either incurs cost (input) or generates revenue (output), the flowchart can help assess the components of a beef enterprise that have the most impact on overall productivity and profitability.

The MLA *Producer's Manual* (MLA 2004) has eight modules (Table 18.3) that provide actions and tools for increasing productivity and profitability.

State coordinators provide national assistance with adopting the information in the MLA manual and encourage best practice. Associated EDGEnetwork workshops include an enterprise health check, sustainable grazing, Prograze (production profit and

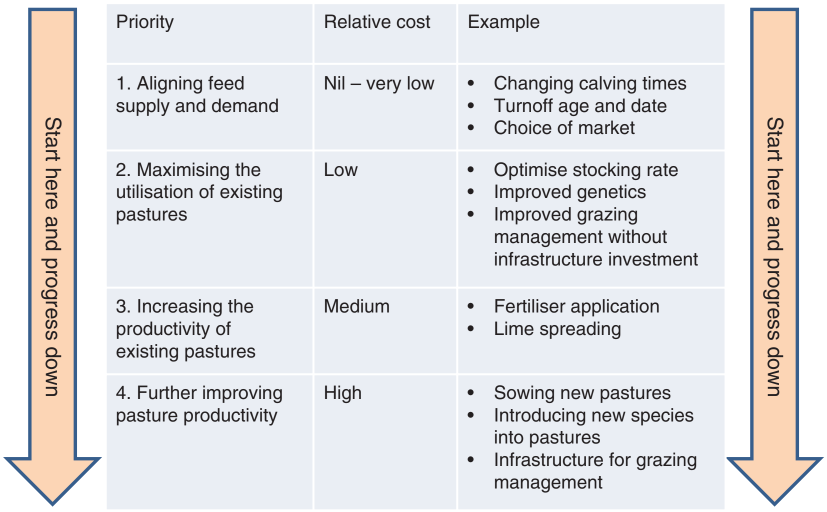
Table 18.2: Priorities for maximising production efficiency

Factors	Process to rank factors
People	a. Goals and visions b. Focus c. Succession d. Roles and responsibilities e. Communication
Business	a. Is the chart of accounts structured for effective analyses? b. A thorough analysis is conducted using ProfitProbe to reveal the strengths and weaknesses of the business against benchmarks and three principles c. Two or three strategies to improve business performance developed per annum
Environment	a. Water distribution and quality b. Infrastructure c. Grazing management is assessed against six principles d. Return on assets on property development options
Production	a. Is the timing of mating correct? b. Reproduction, if applicable, is assessed against eight principles c. Are the genetics suitable for the market and environment? d. What are the nutritional strategies and do they need changing? e. Does the enterprise selection optimise profit? f. Is an enterprise adjustment necessary (e.g. change animal size)

Source: Adapted from McCosker (2011).

sustainability, pasture assessment, livestock production from pasture, production targeting, livestock breeding, pastures and grazing, fodder budgeting and grazing for worm control and putting it together), Beefcheque (soils and fertilisers, rotational and sustainable grazing, beef production, pastures, grazing management, planning for production targets), Better Grazing Decisions, Effective Breeding and BeefNet Product Knowledge workshops. The MLA BeefNet program funded producer groups to set up marketing alliances but was wound up in 2002 with only 20 out of 94 established alliances still trading. Continuity of supply was the main problem with successful alliances focusing on niche markets (Chapter 3).

In Victoria, a workshop program focusing on profitability and sustainability is delivered in collaboration with the BetterBeef Network (2013) covering topics such as pasture growth, pasture utilisation, increasing beef production and maximising herd fertility, business management, benchmarking – financial or production, genetic



Priority	Relative cost	Example
1. Aligning feed supply and demand	Nil – very low	• Changing calving times • Turnoff age and date • Choice of market
2. Maximising the utilisation of existing pastures	Low	• Optimise stocking rate • Improved genetics • Improved grazing management without infrastructure investment
3. Increasing the productivity of existing pastures	Medium	• Fertiliser application • Lime spreading
4. Further improving pasture productivity	High	• Sowing new pastures • Introducing new species into pastures • Infrastructure for grazing management

Figure 18.4: Suggested program for improved productivity in southern herds.
Source: Holmes (2010).

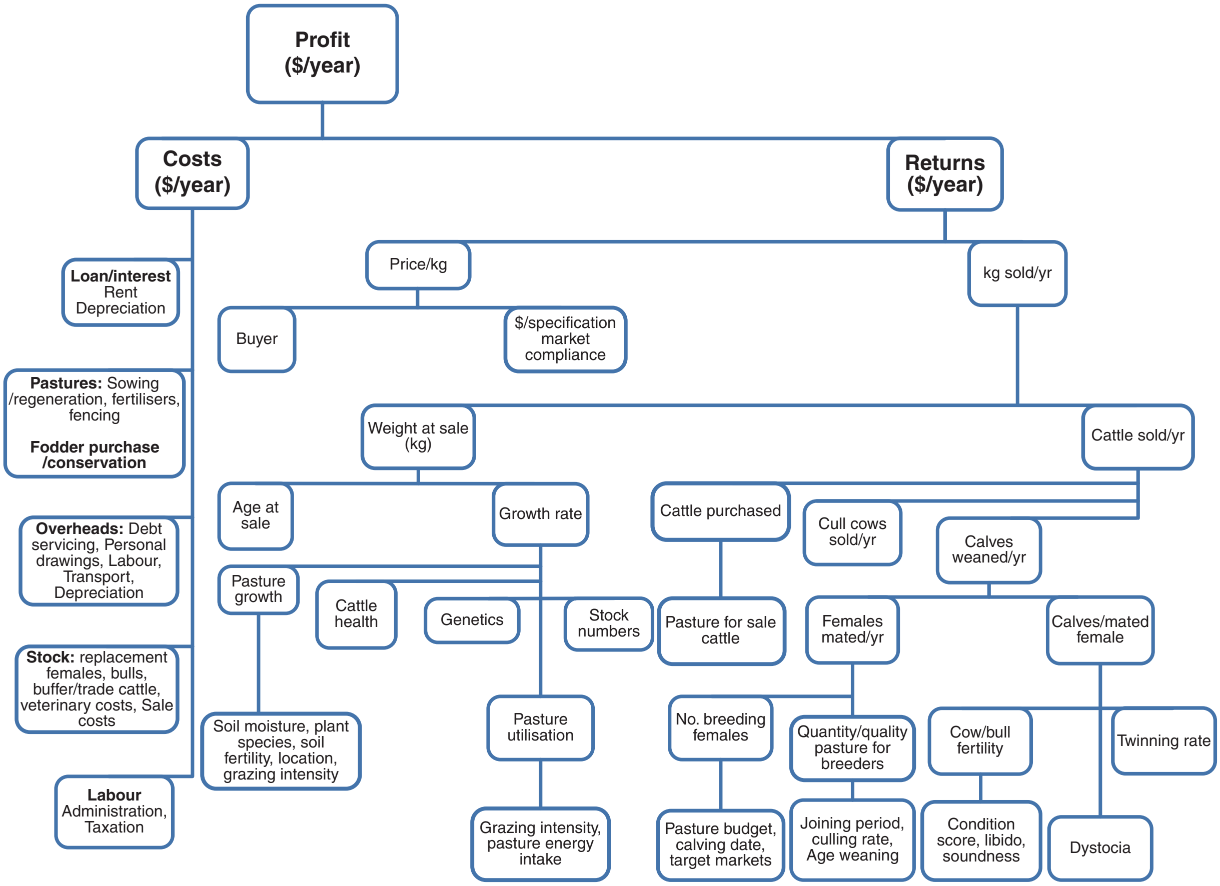


Figure 18.5: Beef enterprise profitablity tree. Source: MLA (2004).

improvement, meeting market specifications, marketing and risk management and herd health.

MLA-funded R&D projects to improve beef production productivity have aimed at increasing reproductive rates, decreasing mortality, reducing age at sale and lowering cost of production. Specifically, they have focused on genetic and genomic information, maternal productivity (efficiency and genotype by nutrition interactions), improved pasture utilisation, new approaches to control diseases and other causes of production loss, alternative grazing systems and evaluation of new pasture species.

There are other services provided by private and public organisations to assist producers with increasing profitability and efficiency. For example, Holmes Sackett provided spreadsheets to its beef clients (D. Sackett, pers. comm.) that included:

- a gross margin analysis for cattle trading;
- bull cost per calf weaned;
- bull team comparison to breed average template;
- cost of long-term fodder storage;
- gross margin and return on investment from grazing crops;
- how much feed would be needed through a drought, and the cost;
- evaluation of returns and cash flow from improving pastures at different rates;
- projection of herd numbers and herd structure for five years;
- calculation of the financial outcome of lot feeding versus selling grain and cattle;
- projection of kg of beef produced for five years;
- calculation of the cost–benefit of an AI program;
- expected return from acquiring more land;
- pasture utilisation calculator (demand versus supply);
- when to sell surplus cattle, i.e. whether to retain cattle into winter or sell over summer to make room for more winter-calving breeders.

Many consultants recommend that producers can increase income by selecting for increased production (weaning weights) and reproduction (e.g. culling dry cows,

Table 18.3: More Beef from Pastures modules

Module	Key actions	Tools
Setting directions	• Set clear business goals and monitor and review progress • Use specialist advisers to decide on business, herd structure and market options to maximise profit • Plan, cost and test beef enterprise options • Determine the sequence of investments (capital and time) that will best meet enterprise goals • Maintain accurate records for comparison of performance with expected targets	• Specifications for a typical enterprise simulation model • Template of partial budget calculations for comparing change scenarios • Enterprise audit sample form <www.farmax.co.nz/Farmax-Pro.aspx> • Cost of production calculator <www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/Cost-of-production-beef>
Tactical stock control	• Predict monthly pasture growth in kg DM/ha/day for a range of weather patterns • Continually match animal feed demand to predicted feed supply • Use partial budgets to assess the benefits and costs of options to match supply to demand	• Guidelines for establishing minimum and maximum limits for whole enterprise pasture availability into the future (or days of feed available)
Pasture growth	• Map grazing lands into pasture zones based on land capability and primary land use • Predict the potential annual pasture production from grazing land using long-term rainfall records • Work out how the water cycle operates on the farm • Adopt new strategies to improve and maintain water use efficiency • Build and maintain soil nutrients for productive pastures and healthy soils • Manipulate pasture composition and productivity by using combinations of grazing management, fertiliser and herbicide application	• Guide to mapping pasture zones and developing the capacity for differential land management • Methodology for assessing soil texture • Visual indicators for identifying waterlogged and salt-affected soils • List of state departments of agriculture websites for further information • Establishing the normal pattern and variability of rainfall • A guide to measuring water use efficiency (WUE) and setting targets for all pasture zones • Methodology for field-based pasture measurements • Table of critical limits for soil nutrients and other ratios important to pasture productivity • Guidelines for pasture nutrient applications • NATA-accredited soil testing laboratories • Guidelines to pasture composition measurements • Sources of information on common pasture species and weeds
Pasture utilisation	• Aim to use 50% or more of green pasture growth to increase livestock production and profitability/ha • Base grazing management on plant growth rate and growth stage for high quality and yield of pasture • Use tactical grazing to meet different animal and pasture objectives at various times • Manage pastures to ensure adequate rest and regrowth before the next grazing	• Pasture rulers, sticks and meters • Methods for setting pasture targets for slow rotations and set stocking • Daily pasture growth estimates for localities and regions across southern Australia • Information sources on pasture utilisation • Grazing management options to convert pastures into beef production • Plant-based grazing management methods
Cattle genetics	• Set the breeding objectives for the enterprise and its target markets • Use BreedObject™ or refer to breed societies' market-based breeding objectives and indices when setting the breeding objective • Assess merits of within-breed selection, changing breeds or crossbreeding	• BreedObject™ software • Sources of information for breed/crossbreed averages for important traits • Guidelines when considering using different breed types • Generic market-based breeding objectives and selection indices

Table 18.3: (*Continued*)

Module	Key actions	Tools
	• Select bulls (or semen) that best fit the enterprise breeding objectives of the herd and provide a return on investment based on $ indices • Bring genetically unrelated bulls into the herd to avoid inbreeding • Mate heifers to bulls with the highest EBV for calving ease if experiencing calving problems	• Bull earning capacity calculator to help predict the estimated earning capacity of each bull based on the $ index value and estimated number of cows to be mated • Calving ease EBVs for bulls available from breed society websites
Weaner throughput	• Assess the fertility and fecundity of herd using cow condition score and heifer liveweight • Select cows capable of conceiving within two mating cycles • Select healthy fertile bulls for mating to achieve normal conception rates and a condensed calving pattern • Supervise calving to increase live calves born • After weaning, cull cows needing intensive calving assistance • Use age, weight and condition score of calves as indicators for earlier weaning • Aim to wean calves when the efficiency of pasture use is greater for the calf alone than for the cow–calf combination • Use yard weaning to lift cattle productivity	• A guide to minimum liveweights of weaner heifers • Condition scoring beef cattle • Evaluating and Reporting Bull Fertility (Australian Association of Cattle Veterinarians) • Calving histogram calculator <http://www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/Calving-histogram-calculator> • Weaning age and projected liveweights • A template for calculating the number of replacement heifers required
Herd health and welfare	• Know the common cattle diseases in the locality and whether they are likely to affect production • Map any historic areas, sites of old yards and stock routes for potential disease • Implement a disease management plan using veterinary advice and thorough risk assessment • Vaccinate against specific diseases that can infect cattle and people • Seek veterinary advice for any unexplained health problem • Quarantine all introduced stock to prevent the transfer of infectious diseases	• Conditions that exist for the development of common cattle diseases • Distribution maps showing trace element and mineral deficiencies for southern Australia • Diagnostic tool for common diseases • Decision support spreadsheet to determine cost-effectiveness of common preventative treatments <http://www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/Health-cost-benefit-calculator> • Management strategies to prevent disease • Diagnostic tool to detect presence of diseases • Conditions and vaccines for prevention of common cattle diseases • Vaccination strategies • Zoonotic diseases of cattle • National Vendor Declaration (NVD) Waybill for cattle • Disease information sources • References to identification of toxic plants and noxious weeds • Disease risk assessment protocols • Diagnostic tools to assess disease status • Strategies to lessen the impact if disease is introduced
Meeting market specifications	• Know the specifications and customer requirements of target markets • Know how to assess and monitor the progress of live animals towards target markets • Manage the grazing system to achieve growth targets and successful market outcomes	• Beef cattle market specifications • Liveweight and fat score ranges over which specifications for most prime beef markets are likely to be achieved • Meat Standards Australia (MSA) Tips and Tools • Range of selling options

(*Continued*)

Table 18.3: (*Continued*)

Module	Key actions	Tools
	• Use high nutritional quality finishing systems to ensure cattle keep growing to slaughter • Seek feedback and implement practices to improve management of the production system. • Regularly evaluate new marketing options and implement those more profitable to the beef enterprise	• Sources of price and other market information

Source: Adapted from MLA (2004).

reduced calving intervals) and matching cow nutrient requirements to available feed resources. The success of these practices is largely due to the availability of relatively inexpensive pastures (Cundiff *et al.* 1993), despite pasture being the greatest expense associated with the production of beef in most countries. In southern Australian pasture-based systems, around 60% of the variable costs of production are related to feed (Griffith *et al.* 2004). As noted earlier, in the USA feed accounts for ~65% of total beef production costs and 60% of the total cost of calf and yearling finishing systems (Loy and Tait 2011). The cost of providing feed to grazing animals includes the costs of land, pasture improvement, fertiliser, irrigation, supplementary feed, the operating and capital costs of plant and machinery, and labour used in feeding (Farquharson 1993).

In many beef production systems a large proportion (65–85%) of the feed is used by the cow breeding herd (Montaño-Bermudez *et al.* 1990), while young growing animals consume feed which is often of higher value. Loy and Tait (2011) stated that the cow–calf segment consumed 70% of feed energy, with 30% used in the growing and finishing systems. Cundiff *et al.* (1993) noted that 72% of all feed utilised in US beef production is fed to cows and calves before weaning.

Many studies of feed efficiency have concentrated on young growing cattle, whereas the cow herd has the highest maintenance requirements. Feed cost for maintenance is estimated to represent at least 60–65% of the total feed requirements for the cow herd (Montaño-Bermudez *et al.* 1990). The cost of feeding beef cows accounts for 60–65% of the total cost of production in a cow–calf operation (Kaliel and Kotowich 2002). Supplementary feeding with hay, grain and silage adds further to the cost of feeding cattle, so the cost of feed is around 70% of the variable cost of operating a feedlot (Taylor and Field 1999; Chapter 12). The efficiency of feed utilisation of the whole farm production system therefore greatly impacts on enterprise productivity.

Beef producers often routinely record outputs (e.g. liveweight gain, LW) which determine the value of product sold, but not so often the inputs (e.g. feed cost) that define the cost of beef production. The inability to routinely measure pasture feed intake and therefore efficiency in large numbers of cattle has precluded the efficient application of breeding and selection despite the moderate heritability of feed intake (Chapter 17).

WEANER PRODUCTION AND THROUGHPUT

Weaning rate

The MLA commissioned situation analysis reports for both the northern and southern beef industries in 2010 (McCosker *et al.* 2010; Holmes 2010). The northern report highlighted the need for industry to 'dramatically lift the use of objective measurement' and 'identify issues (e.g. disease and nutritional issues) restricting performance in the extensive breeder herds. This would include identifying the relative influence of genetics (mature weight of cows, lactational anoestrus etc.), nutrition (are there any effects from unrecognised deficiencies) and timing of activities (controlled mating, mob segregation vs continuous mating and cattle harvesting). This is needed to organise effective and targeted extension programmes. A modelling approach may be the first step.' The southern report highlighted the importance of optimising herd weaning weight per hectare through 'cost-effective management of nutrition, breeding and weaning to increase the rate of LW gain and consistency of weaning weights'.

The Cooperative Research Centre (CRC) for Beef Genetic Technologies ran large projects in northern and southern Australia from 2005–12 to address issues of potential for genetic improvement in weaning rate, specifically by focusing on components of calving interval. Calving interval integrates some of the key factors identified in Table 18.2. In Brahman cattle, the length of post-partum anoestrus is highly heritable in first lactation females (0.52) and is moderately heritable in tropical composites (0.26) (Hawken *et al.* 2012). Genetic progress is limited by recording in bull breeding herds and accuracy of estimated breeding values (EBVs) in young bulls (Chapter 17).

In southern cattle under restricted nutrition, calving rate is correlated with genetic fatness of the cow. Genetic progress for calving rate is currently zero because the studs making genetic progress in other traits utilise a lot of AI, which requires oestrus synchronisation which prevents recording of traits associated with post-partum anoestrus. In both the north and south, there is a need for recording systems that have the dual role of aiding current management decisions and providing phenotypes for genetic improvement.

Over 600 heifers were raised on southern Beef CRCs at Struan in South Australia and Vasse in Western Australia. Over 500 of them were kept and raised for three parities under high or low nutrition (equivalent to stocking rate differences) levels, with weekly feed intake measurements of replicate groups. In terms of managing heifers (12–18 months of age) to maximise pregnancy rate, the most important factor by far was weight, then fat and then age. Weaning rates were 10% lower than pregnancy rates primarily due to foetal losses and calf death in the first three days.

In southern Australia, where weaning rates are higher than in the north, it is recommended to pregnancy-test cows around six months after calving (commonly at calf weaning time) or six weeks after the end of joining. Dry cows (non-pregnant but could still be lactating) should be removed from the breeding herd after weaning: the feed cost of maintaining them for 18 months before they would calve again is too great and at weaning time they will usually be in reasonable condition for sale. In northern Australia, weaning rates are lower, feed costs cheaper, transport costs higher and price of cull cow beef lower, so the decision to sell dry cows is less clear.

In addition to the immediate production benefit from selling dry cows, there is a small long-term genetic benefit of breeding female replacements only from cows that continue to calve on an annual cycle. That said, selection intensity for cows is very low compared to genetic gains through selecting superior bulls (Chapter 17). Dry (non-lactating) cows can be sold for meat and sales from cull cows can sometimes represent 40% of gross herd income (MLA 2012b).

Well-grown heifers will normally reach puberty (i.e. start oestrus cycling) by 12 months of age. Jones *et al.* (2013) produced growth targets for purebred Angus heifers at 14 months of age (pre-joining) (Table 18.4). With the possible exception of drought conditions, in southern Australia the extra feed cost of growing heifers to three years before calving is acceptable only where beef cattle are run under harsh conditions (e.g. nutrition, cold, topography). However, in northern Australia where feed quality (rather than quantity) is limiting, there may be little control over this. That said, in better parts of northern Australia such as the Brigalow-Belah belt, it is good to aim for heifers to calve at two years and maintain an annual production cycle, and there are definitely cows that can achieve this.

Since many producers are now using a restricted joining time (six weeks) for heifers and Angus cattle are now much larger than they were formerly (Barwick and Henzell 2005), based on the results in Table 18.4 it could be recommended that Angus heifers be grown to 400 kg before mating, depending on stocking rate. This may seem excessive, but it matches with old recommendations of mating at 60–65% of mature weight, since many mature cows are now over 600 kg.

Jones *et al.* (2013) demonstrated that the EBV with the strongest relationship to heifer pregnancy rate was days to calving (shorter is better), the trait that is designed to reflect genetic differences in calving time and subsequent weaning rate. There are weak relationships with EBVs for scrotal size in bulls (bigger) and fat depth (fatter), both positively related to age at puberty.

The concern for producers is often pregnancy rates in first calving cows, as these are still growing as well as lactating and are required to resume oestrus cycling just two months after calving. In the Beef CRC maternal productivity project, the pregnancy rate (second pregnancy) of first lactation cows was 91%, leading to a weaning rate of 81%, which is moderate. There was still a relationship between pre-joining weight and pregnancy rate, but it was not as strong as for heifers. However, not surprisingly, there was a relationship with days in lactation (Table 18.5). There was not a strong relationship between pre-joining weight and pregnancy rate in mature cows, demonstrating that most of the variation in lifetime weaning rate occurs during the first two joinings for the conditions studied.

The northern CRC project also found that lifetime productivity was mostly associated with calving success at the first two opportunities. Calving success for heifers was associated with age at puberty, which was highly heritable in Brahman (0.57) and tropical composite (0.52)

Table 18.4: Predicted pregnancy rate (%) for a range of pre-joining (400 day) weights and rib fat depths of Angus heifers after a six- or nine-week joining

	Rib fat (mm)								
Weight (kg)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Six-week joining									
250	49	52	54	57	59	62	*	*	*
300	59	61	64	66	68	71	73	75	77
350	68	70	72	74	76	78	80	82	83
400	76	78	79	81	83	84	86	87	88
450	82	84	85	86	88	89	90	91	92
500	*	*	89	90	91	92	93	94	94
Nine-week joining									
250	64	69	74	78	82	85	*	*	*
300	71	76	80	83	86	89	91	93	94
350	78	81	85	88	90	92	94	95	96
400	83	86	89	91	93	94	95	96	97
450	87	90	92	93	95	96	97	97	98
500	*	*	94	95	96	97	98	98	98

* No animals in this range.
Shading represents low, medium and high levels.
Body condition score in heifers: ~2 = 2–4 mm, 3 = 5–7 mm, 4 = 8–10 mm rib fat depth.
Source: Jones *et al.* (2013).

cattle (Johnston *et al*. 2009). Success at second calving was primarily a function of post-partum anoestrus interval which, in Brahman cattle, also had a much higher heritability (0.52; Hawken *et al*. 2012) than reproductive traits generally.

While it is possible to have some control on stocking rates, supplementary feeding strategies in northern Australia are limited because of the extensive conditions. Thus, genetic selection is one of the greatest tools for improvement. It is encouraging that weaning rate, one of the strongest profit drivers, can be improved genetically. The challenge for the industry is to get good EBVs for young female fertility, on young bulls. Obviously female fertility cannot be measured in bulls, so this is an area where genomic selection should have a major role to play.

Weaning time and growth rate of calves post-weaning

One of the issues affecting efficiency of production systems is the ideal milk yield and length of lactation.

Table 18.5: Expected pregnancy rates (%) at range of weights and time from calving to start of mating period (second joining) for 26-month-old Angus cows

	Days in lactation								
Weight (kg)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
350	59	63	66	70	74	77	81	83	86
400	62	65	69	73	76	80	83	85	87
450	64	68	72	75	79	82	84	87	89
500	67	71	74	78	81	84	86	88	90
550	70	73	77	80	83	85	88	90	92
600	72	76	79	82	85	87	89	91	93
650	75	78	81	84	86	89	91	92	94
700	77	80	83	86	88	90	92	93	95

Shading represents low, medium and high levels.

Early in lactation, calf intake is limited, peaking at around 11 L/day at six weeks (Dove and Axelson 1979). Dairy cross cows have been useful for producing calves for the vealer market in an autumn calving system in southern Australia (Chapter 10), but (anecdotally) may produce too much milk when spring calving. Given that calves are seldom sold for slaughter at weaning, milk production potential is generally not a limiting factor. Thus, the major issue faced is the length of lactation (i.e. age to wean calves).

In recent years there has been a push towards early weaning of calves in southern Australia (Wolcott *et al.* 2010). The logic is based on the energetic inefficiency of milk production (53%) and on claims of greater performance by speeding rumen development. Ensuring cows don't become overfat must then be managed by increasing stocking rates. It costs ~5.7 MJ to produce a litre of milk that contains ~3.0 MJ, so (in theory) there is a 2.7 MJ energy loss in milk synthesis relative to the calf eating forage or supplement directly. Early weaning is demonstrated by hand-raising of dairy calves that are commonly weaned at four to 10 weeks (Dairy Australia 2011). Thus, the primary reason for suckling is for the cow to be able to convert low-quality feed more efficiently than if the calf ate the feed directly. Young calves have a higher requirement for protein (minimum 15%) for unrestricted growth. Tables of energy and protein needs for calves are given in various feed standard publications (e.g. Rattray *et al.* 2007).

Calves under six months need high-quality feed (at least 11 MJ ME/kg DM, 16% crude protein), and if there is high-quality pasture available this could be an energetically efficient option. However, if calves require expensive supplementary feed, then this could be prohibitively expensive. The cost savings are presented in Fig. 18.6, based on our equation:

$$\text{Saving from early weaning} = 5.7 \times \text{Cow} - 3.0 \times \text{Calf}$$

where Cow = cost per MJ of cow feed, Calf = cost per MJ of calf feed.

Simply put, there is almost twice as much energy required for a calf if its food energy comes from milk compared to feed. However, if the calf's feed is more than double the cost (per MJ ME) than the cow's feed, then weaning comes at a cost (Fig. 18.6). During a drought, both cow and calf feed is expensive so early weaning is often a sensible strategy and is seen as the best form of helping the cow. During better seasonal conditions, cow and calf feed is quite cheap when grazing and towards the end of spring, given that most properties have a diversity of paddocks, it is often sensible to put cows on low-quality and calves on high-quality pasture. Only in specific circumstances with carefully modelled budgets should beef calves be weaned onto high-quality pellet type feeds; these can result in good production but cost more than $80/t.

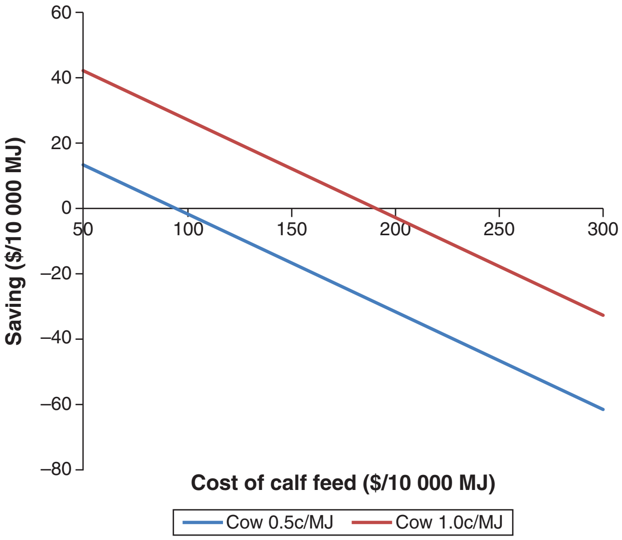


Figure 18.6: Savings from early weaning of calves, assuming cost of cow feed is 0.5c/MJ ($50/t of 10 MJ ME/kg DM). Figures approximate price per tonne but are presented in energy units because the energy content of cow and calf feeds can be different.

In extensive operations with low-quality feed, common in northern Australia, calf weaning time is decided more by the requirements of the cow than the calf (Chapter 14). During the dry season the feed is so low in digestibility that cows cannot eat sufficient grass to maintain body condition as well as lactation, and early weaning is a way of managing cow condition (Alexander 1965).

One of the claims of early weaning is early rumen development and that calves will be more efficient, but there is no solid evidence for this claim. One of the few studies that included an early weaning treatment found that calves conventionally weaned at 259 days of age were 19 kg heavier at the same age and this difference persisted during a feed efficiency test (Wolcott *et al.* 2010). The early weaned animals ate slightly less during test, but there was no difference in efficiency when measured as residual feed intake or feed conversion ratio.

Walker *et al.* (2007) published results from trials that had already led to rapid change in management of weaner cattle in the southern beef industry. Calves were placed into three treatments immediately after weaning: paddock, yards for 10 days with hay or silage, yards with same feed and daily training to find the feedbunk with some grain. There was an overlay treatment of ± vaccination for bovine respiratory disease. Measurements included adaption and performance when the calves went for feedlot finishing following backgrounding. There was no effect of training in the yards, but yard-weaned calves adapted faster, had fewer hospital visits and grew 23% faster during the first 36 days in the feedlot compared to paddock-weaned calves. Vaccinated calves were healthier and grew 17% faster than unvaccinated calves. The authors concluded that the biggest effect was due to socialisation: yard-weaned calves that had been forced to socialise were affected less by this when faced with the multiple stressors at feedlot entry (i.e. transport, mixing, new feeding system, disease exposure).

Greenwood *et al.* (2006) reported results from a trial designed to test effects of early calf growth path (weight for age) on subsequent carcass and meat quality traits. The calves were sired by high-yield (Piedmontese) or high-marbling (Wagyu) bulls to generate diverse carcass composition, and received nutrition treatments to achieve high or low pre-weaning and high or low post-weaning growth. The differences in birth weight between high and low nutrition were 36% (38.8 kg versus 28.6 kg) and the difference in growth rate treatments was 58% (875 g/day versus 554 g/day). The focus of the trial was on early growth path effects on later performance, not on factors such as dystocia which could be an issue in maiden cows under high pre-natal nutrition. All cattle were feedlot finished and slaughtered at ~30 months of age. In general, there were no large interactions between treatments but differences between growth paths on carcass traits were basically a function of carcass weight. High birth weight calves weighed 56 kg heavier at 30 months, had 32 kg heavier carcasses and yielded 18 kg more beef than low birth weight calves and there was little impact on carcass composition. Similarly, calves grown faster to weaning were 40 kg heavier at 30 months, had 25 kg heavier carcasses and yielded 12 kg more beef. Thus, the primary effect of slow growth was on weight for age so if it took longer for low growth treatments to reach a carcass weight, then the only real quality difference was in ossification although this wasn't even significant for the post-natal growth treatment. In conclusion, there were no large effects on carcass quality and no large interactions between treatments. This provides confidence for models to be developed that predict carcass outcomes based on growth. Indeed, it led to the development of BeefSpecs (DPI 2013; Walmsley *et al.* 2010).

MATCHING FEED DEMAND AND REQUIREMENTS IN THE ANNUAL PRODUCTION CYCLE

Matching growth and milk production to the available feed resources is key to creating efficient cows (Greiner 2009; Table 18.1; Chapter 15). The seasonal availability of pasture varies greatly in most countries. The most important factor in matching feed supply and feed demand is changing the time of calving. This is affected by other management requirements on farm (e.g. sheep or cropping) and market specifications such as premium prices for weaner cattle.

In contrast to other livestock species (i.e. sheep and pigs), cattle are expected to conceive while lactating and soon after the period of peak lactation. The average gestation period for beef cattle varies with breed. Reynolds *et al.* (1980) reported purebred Angus gestation length of 280 days and Brahman 291 days, with crossbreds intermediate. For a cow to remain on an annual production cycle it has no more than 12 weeks to become pregnant after calving. This period is typically associated with negative energy balance because of the demands of lactation (Guilbert and McDonald 1934).

There are three strategies to manage the energy requirement of lactating cows leading into the mating period. First, cows need to have good body condition (at least 3) before calving to ensure there are sufficient body reserves to meet the requirements of parturition and lactation. Second, pasture feed should be supplemented with good-quality hay to ensure adequate nutrition, but this has a machinery and time cost. Third, cows should be mated at a time of peak pasture feed supply in terms of quantity and quality.

Pasture feed supply varies significantly throughout the year, especially when quality is taken into account (Chapter 15). While productivity differs between regions, the growth rate pattern through the year is the primary driver of management decisions, so pasture growth in regions has been scaled for comparison (Fig. 18.7). Productivity differences between regions are driven by rainfall and temperature. Pasture quality is a secondary driver, that varies throughout the year and between regions (Fig. 18.8). One of the main differences is that the tropical regions where C4 grasses predominate never have periods of high quality (>10 MJ ME/kg DM) relative to the southern Australian sites (Fig. 18.8).

The best production system to match pasture feed supply and demand is one that has the greatest peaks and troughs of feed demand, because feed supply is so variable.

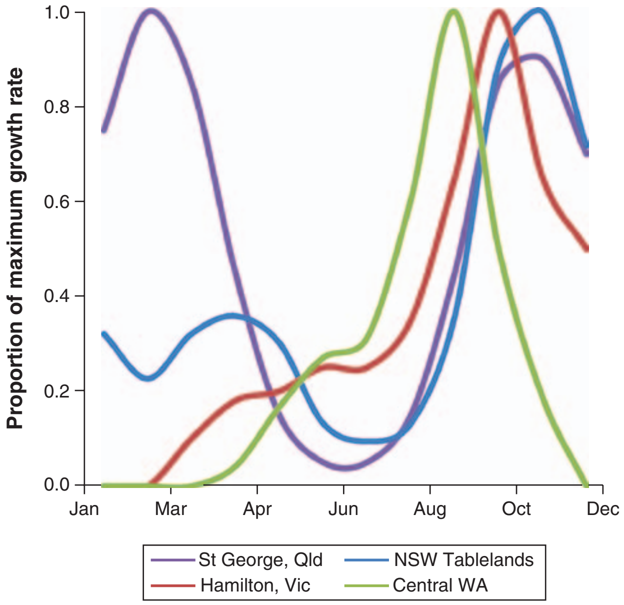


Figure 18.7: Annual relative pasture growth rates for different Australian regions. Source: Adapted from MLA (2012b).

Thus, independent of the specific feed supply curve for a region, feed or energy demand can be modelled. This has been done, based on the following assumptions:

- maintenance requirement of cows = $0.62\text{Wt}^{0.75}$ (MJ/day) where Wt is the cow weight (assumed 600 kg) and the energy requirement is based on analysis of reported values (Nicol and Brookes 2007);
- calf growth rate based on experience and the curve for a 600 kg cow (Fig. 18.9);
- calves are weaned at six months of age;
- milk production rises to a peak of 6 L/day and declines to 3 L/day;
- energy cost of milk production is 5.7 MJ/kg (Nicol and Brookes 2007) and energy content of milk is 3 MJ/kg;
- energy density of fat is 39.3 MJ/kg (ARC 1980), efficiency of deposition is 0.7 and mobilisation is 0.84 (Geay 1984);
- cows can gain or lose fat up to 0.33 kg/day to a maximum of 10% of LW, so ± 60 kg.

The two extreme examples modelled are gaining fat while lactating but losing weight (fat and muscle) while dry, or the opposite (Fig. 18.9). In southern Australia, cows calving just before the spring flush can gain weight and condition (fat and muscle) while lactating. In contrast, those calving in autumn lose weight in early lactation and must be in condition score 3 before calving to have a reasonable chance of getting pregnant again.

While there is no existing research data on this, there is an interesting case study in south-eastern South Australia where some large commercial breeders run their cow herds effectively like an extensive station, despite reasonable rainfall, because of lack of labour. On these properties, even for cows that have been brought in from stations and have calved throughout the year, after a few

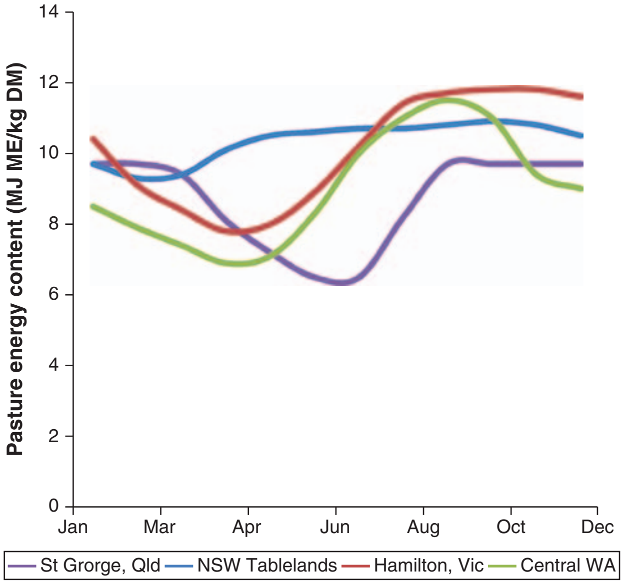


Figure 18.8: Annual variation in pasture quality for different Australian regions (and pasture types). Source: Adapted from MLA (2012b).

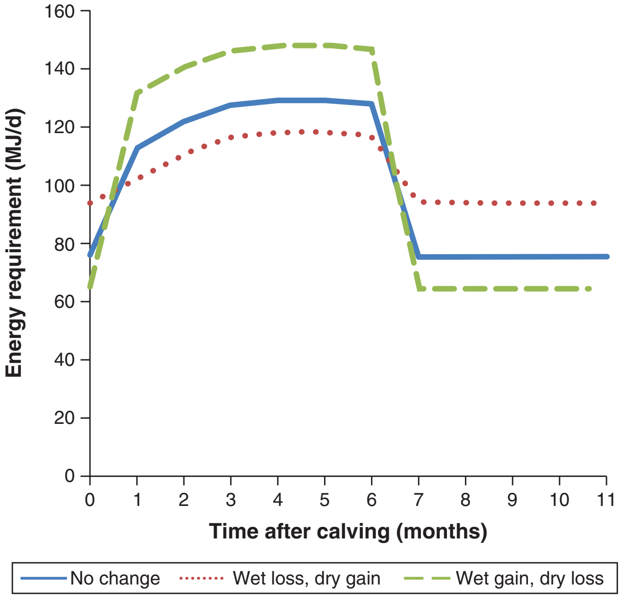


Figure 18.9: Energy requirements of cows and calves (weaned at six months) allowing for changes in body composition at different times relative to calving.

seasons the majority of cows calve in August. The reason for this is that they are in peak condition and therefore most likely to cycle after spring and so most conceive in November.

Feed demand (Fig. 18.10) has been modelled using the feed demand calculator (MLA 2012a). The NSW tablelands site has a growth pattern closer to northern Australia but pasture quality like southern Australia. The principles of matching supply and demand remain the same regardless of location. However, on extensive properties, supplementary feeding strategies may not be an option (Chapter 16). Note that the peak growth at the Queensland site occurs in February, at NSW in November, at Victoria in October and at Western Australia in September (Fig. 18.7). To best match feed demand and supply, calving should begin about two months before this point and mating soon after.

Given feed supply variation during most years, a breeder herd cannot usually eat the difference between the trough and peak feed supply (Fig. 18.10). The ideal from a production viewpoint is to trade steers. In the scenario above, 1500 steers could be bought in October and sold at the end of January. The amount of feed utilised would be the same, but far less supplementary feed would be required. This is good in theory, but in practice it would depend on being able to source the steers, the difference in buying and selling price per kg and transaction costs (transport, commission, levies). In practice, a breeder herd and opportunistic growing out of home-bred calves and traded cattle seems to be a good mix long-term.

FEED USE EFFICIENCY

Feed use efficiency of the pasture and supplement consumed (animal product/feed intake) of a herd is the sum of the feed use efficiency of the individuals making up the herd. It is the focus of this section. The efficiency of use of available pasture also depends on the number of animals grazed, i.e. stocking rate (Chapter 15).

Biological efficiency depends upon the interaction between genetic potential and the environment; specifically, the availability and variability of feed resources. Cattle partition food energy in the following order: maintenance, growth, lactation, reproduction (Freer *et al.* 2007). Ritchie (1995) described high-maintenance cows as those that tend to have high milk production, high visceral organ weight, high body lean mass, low body fat mass, high output and high input. High-maintenance cattle also tend to reach puberty at a later age, unless they have been selected for milk production (Arango and Van Vleck 2002). Low-maintenance cows tend to be low in milk production, low in visceral organ weight, low in body lean mass, high in body fat mass, low output and low input (Ritchie 1995). Thus low-maintenance requirements don't necessarily equate with high efficiency, as maintenance energy does not indicate output level. Feed efficiency in the beef industry has been reviewed by Hill (2012).

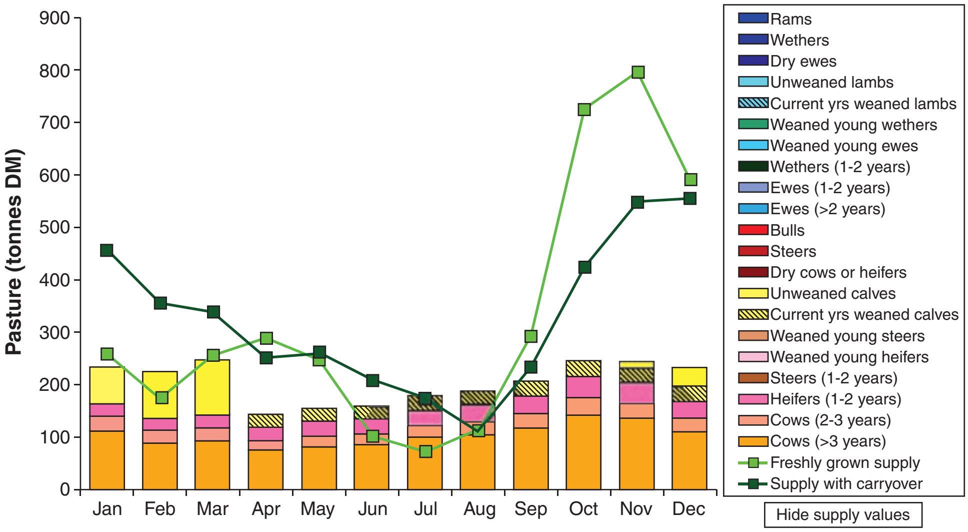


Figure 18.10: Example herd structure showing feed supply and demand based on a 500 cow herd on 200 ha at Hamilton, Victoria, including breeding heifer replacements. Weaners and cull cows and heifers are sold in mid-December.

Jenkins and Ferrell (1994) ranked efficiency among three British and six Continental breeds on different feed intakes. At lower intakes, breeds that had moderate growth and milk production (i.e. Angus, Red Poll, Pinzgauer) were more efficient because of higher conception rates. Continental breeds with greater growth and milk production had less energy for reproduction. At higher intakes, the Continental breeds were more efficient at producing heavier calves while British breed cows became fat rather than producing heavier calves.

Jenkins and Ferrell (1994) examined a range of *Bos taurus* crosses at a range of feeding levels (Fig. 18.11). They demonstrated that, at the breed level, genotype by environment interactions exist within southern Australian type production systems. When feed was restricted, the most efficient breeds were British types that were smaller and fatter than European type breeds. The large and lean European breeds were the most productive in high feeding level systems. High feeding could occur on farms with lower stocking rate, more supplementary feeding or just good seasonal conditions. The fact that British types were more efficient with less feed, which could be analogous to poor seasons, means they are regarded as less risky given Australia's highly variable climate. The breed differences reported match breeder experience, where European cattle are regarded as 'good time' cattle.

Vargas *et al.* (1999) studied efficiency in three calvings of small, medium, and large Brahman cattle in a subtropical production system in Florida. The small- and medium-framed cattle were more efficient for the first two calvings, but by the third, when the large-framed cattle had reached their full growth potential, the large cattle were more biologically efficient. Maximum efficiency occurs at a level of feed intake that does not limit reproduction and also provides sufficient energy for milk production to meet the growth potential of the breed as expressed in the calf, but does not exceed the genetic potential for either reproduction or production (Jenkins and Ferrell 2002).

Traditionally, selection for growth rate has received most emphasis. However, its effects on enterprise efficiency and profitability can be questioned. Increased mature size and increased energy cost of maintaining females (Barlow 1984; Scholtz and Roux 1984) and increased methane production (discussed below) can be expected. Thompson and Barlow (1986) showed that greater improvements in enterprise efficiency would result from an improvement in feed conversion efficiency of the growing animal and reduction in feed intake of the mature dam.

Cundiff *et al.* (1993) noted that selection for reduced feed intake alone inevitably results in a correlated reduction in bodyweight. Therefore, various functions of output of beef per unit of feed are used as measures of feed efficiency. The most common index of efficiency is gross efficiency, defined as the ratio of output (e.g. gain) over feed inputs (e.g. kg feed eaten). Feed conversion ratio (FCR) is the inverse of gross efficiency and is used widely in the chicken and pig industries.

Koots *et al.* (1994) and many others have reported very negative genetic correlations between FCR and growth rate and size in beef cattle, so selection to reduce FCR and thus improve efficiency would be accompanied by an

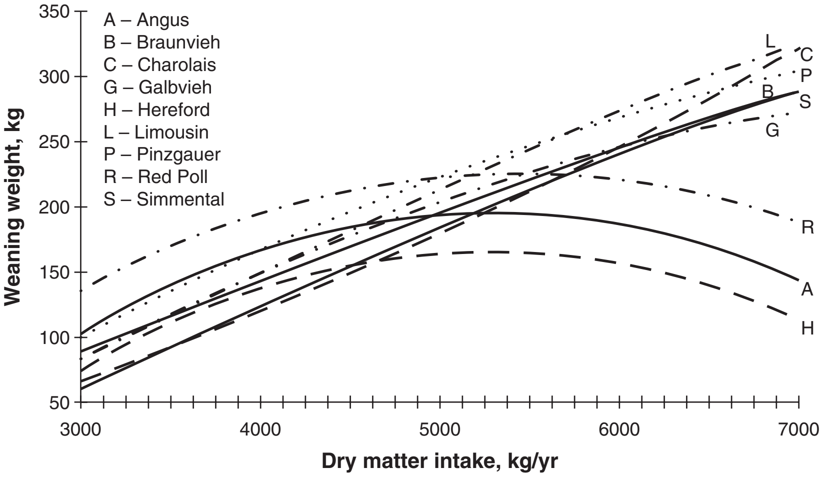


Figure 18.11: Breed by feed availability interactions for weight of calf weaned per cow joined. Source: Adapted from Jenkins and Ferrell (1994).

increase in growth rate and mature cow size. A second disadvantage of selection for FCR relates to problems associated with selection on ratio measurements (Gunsett 1986), involving two different traits (in this case, feed intake and growth) with different variances.

Selection for faster growth rate improves feed efficiency mainly through a reduction in maintenance costs, due to fewer days being needed to reach a target weight, but it leads to higher mature weights and maintenance energy costs for breeding cows. Two animals with similar FCR may have very different feed intakes and rates of gain. The same animal at different intake levels can have a different FCR, even though its genetics haven't changed. FCR has a low genetic correlation between the trait measured in the young animal and that measured in the adult (Archer *et al.* 2002) and is not recommended as a breeding trait. However, FCR is important in the feedlot as FCR multiplied by the cost of the ration determines the feed cost of gain, which is the primary profit driver in feedlots (Chapter 11). Average daily gain (ADG) is of secondary importance to FCR in that context.

Breedplan started providing EBVs for residual feed intake (RFI) from 2002 (Arthur and Herd 2005), but it has not been used very much by breeders (Barwick *et al.* 2011). The concept of RFI was first described for cattle by Koch *et al.* (1963). The authors examined various indexes for calculating feed efficiency and suggested that feed intake could be adjusted for LW and weight gain, effectively partitioning feed intake into two components: 1) the feed intake expected for the given level of production, and 2) a residual portion. The residual portion (RFI) can be used to identify those animals that deviate from their expected level of feed intake, and they can be classified as high efficiency (negative residual intake) or low efficiency (positive residual intake). RFI is measured over 50–70 days (Archer *et al.* 1997, 1998, 1999; Kennedy *et al.* 1993). The main advantage of using RFI instead of FCR as an efficiency trait is that RFI is not a ratio trait, so selection to reduce RFI should reduce feed intake and contribute towards both pre-weaning and post-weaning profitability, without reducing growth or correlated responses in maturity type (Archer *et al.* 1997, 1998; Herd and Bishop 2000).

RFI, or net feed intake (NFI) as is it sometimes called, is phenotypically independent of weight and gain. Kennedy *et al.* (1993) showed that it is not necessarily genetically independent. Considerable genetic variation in RFI exists in beef cattle. Heritability estimates for RFI have been moderate, ranging from 0.26 to 0.43 (Montanholi 2007). Pitchford (2004) calculated a mean heritability of 0.25 for RFI from 35 estimates across seven species/types. Genetic correlations of RFI with feed intake have been large and positive, suggesting that improvement would produce a correlated response of decreased feed intake. RFI estimated by genetic regression results in a zero genetic correlation with its predictors, which reduces concerns over long-term antagonistic responses such as increased mature size and maintenance requirements.

The computation of RFI requires the estimation of expected feed intake or its direct measurement. Intake can be predicted from production data by using feeding standards (NRC 1996) (but this does not help differentiate animals), by using feed intake prediction models or by phenotypic or genetic regression using actual feed test data (Kennedy *et al.* 1993). Calculation of RFI using the phenotypic regression approach can generally be summarised as:

$$y = b_0 + b_1.\mathrm{ADG} + b_2.\mathrm{MWT} + \mathrm{RFI}$$

where

y = daily feed intake;

b_0 = the regression intercept;

b_1 = the partial regression on ADG;

b_2 = the partial regression on mid-weight during the test (MWT).

In Australia, the standard is to regress on metabolic mid-weight ($\mathrm{MWT}^{0.75}$) (Archer *et al.* 1998). This equation was designed for young and growing cattle but the equations can be adapted for other types of cattle, such as pregnant beef cows (Montanholi *et al.* 2010).

However, differences in efficiencies of growth may also be due to differences in composition of LW gain as water and protein have lower energy content than fat (Ferrell and Jenkins 1998). Higher maintenance costs are often associated with greater visceral organ weights, increased feed intake (Ferrell and Jenkins 1998) and higher body protein (Pullar and Webster 1977). Basarab *et al.* (2003) suggested that RFI should be adjusted for changes in the chemical composition of gain, possibly by including ultrasound backfat thickness and marbling score in the equation for determining RFI. Correction of RFI for body composition is more routine in the poultry (Luiting and Urff 1991) and pig (Bunter *et al.* 2010) industries and helps overcome concerns about negative correlations with reproductive performance.

Much of the variation in RFI reflects variation in the maintenance term and this may reflect variation in physical activity. In dairy cows, the heritability of RFI has been estimated to be essentially zero (Veerkamp *et al.* 1995). The proportion of the food eaten that goes to maintenance is higher in hens than cows. The mean and variance of level of physical activity seem to be greater in hens (Emmans and Kyriazakis 2000). They suggested that RFI selection is more useful the higher maintenance is as a proportion of total energy intake, the larger activity is as a proportion of maintenance, and the larger the genetic variation in physical activity between animals. They suggested that RFI is more suited to use in poultry.

Many other measures and definitions of efficiency exist (e.g. cow/calf efficiency, maintenance efficiency) (Archer *et al.* 1999). Clear definition of a trait is important when using selection indices (Chapter 17). Barwick (2002) discussed the effect of trait definition and the derivation of economic values for costing feed. Choice of trait depends on the data being recorded, the model used to compute EBVs, the method used to construct indices and likely uptake by breeders.

Richardson *et al.* (1998) showed that the Angus steer progeny of parents selected for low post-weaning RFI were more feed-efficient in the feedlot than the steer progeny of parents selected for high post-weaning RFI, with no compromise in growth performance or carcass characteristics. Arthur *et al.* (2001) studied records on 1180 young Angus bulls and heifers involved in 70 day performance tests, and data from 26 049 animals from the Angus Society of Australia. They estimated direct heritability for 200 day weight, 400 day weight, rib fat depth, ADG, feed conversion and RFI as 0.17, 0.27, 0.35, 0.28, 0.29 and 0.39, respectively. FCR was genetically ($r_g = 0.66$) and phenotypically ($r_p = 0.53$) correlated with RFI. FCR was correlated ($r_g = -0.62$, $r_p = -0.74$) with ADG, whereas RFI was not ($r_g = -0.04$, $r_p = -0.06$). Genetically, both RFI and FCR were negatively correlated with 200 day weight ($r_g = -0.45$ and -0.21) and 400 day weight ($r_g = -0.26$ and -0.09). The correlations between feed intake and FCR ($r_g = 0.31$, $r_p = 0.23$), feed intake and RFI ($r_g = 0.69$, $r_p = 0.72$), and rib fat depth and RFI ($r_g = 0.17$, $r_p = 0.14$) were non-zero: this indicated that genetic improvement in feed efficiency can be achieved through selection and, in general, correlated responses in growth and the other post-weaning traits will be minimal.

The reasons for the variation in RFI in cattle are still not fully understood but are likely to include differences in feeding behaviour (Richardson and Herd 2004; Dobos and Herd 2008). Robinson and Oddy (2004) found that feedlot RFI was positively correlated with time spent feeding ($r_g = 0.35$, $r_p = 0.16$,) and number of feeding sessions per day ($r_g = 0.43$, $r_p = 0.18$); thus RFI was associated with more time spent feeding and more feeding sessions per day. Feeding behaviour is complex, so Stroup *et al.* (1987) suggested the use of finite Fourier transformations and spectral analysis to account for the cyclic variation in feed intake data. This has been used to study feeding behaviour of steers in feedlots (Wilson *et al.* 2005) and grazing behaviour in cattle (Deswysen *et al.* 1993; Seman *et al.* 1997, 1999; Dobos 2007), and to quantify differences in feeding patterns of Angus feedlot steers genetically divergent in RFI (Dobos and Herd 2008). Mean daily dry matter intake (DMI) was 11.9 kg/day and 12.7 kg/day over the 72-day feeding period for low- and high-RFI steers, respectively. The high-RFI steers exhibited different temporal cycles from the low-RFI steers in daily feed intake and time spent feeding. However, patterns of number of eating sessions, feeding rate, the time spent eating and number of eating sessions were similar.

Richardson and Herd (2004) found that protein turnover might be a meaningful source of variation for RFI. Ion pumping and proton leakage also contribute to the total maintenance energy requirements (Rolfe *et al.* 1999), the three processes collectively accounting for 60–70% of the total energy requirements for maintenance, which basically represent the animals' energetic inefficiency (Montanholi 2007). The Na^+/K+ pump, controlled by the enzyme Na^+/K+-ATPase, accounts for 20–30% of the total maintenance energy requirements (Baldwin *et al.* 1980). The proton leakage (H^+) across the mitochondrial membrane is partially catalysed by uncoupling proteins which decrease energy efficiency, because energy is lost as heat rather than used as an energy source by the cells. These proteins have an important role in the total heat production in mammals, representing around 20% of the maintenance energy requirements (Rolfe *et al.* 1999). Kolath et al. (2006a, b) found that mitochondrial function was not different between high- and low-RFI steers but that the rate of mitochondrial respiration increased in low-RFI steers, suggesting a better efficiency of electron transfer.

Around 40% of the maintenance energy requirements are due to the gastrointestinal tract (16–29%) and liver (20–26%) metabolism (Cundiff *et al.* 1993). Cortisol, an adrenal glucorticoid hormone, is a key component of the physiological response to stress and plays an important role in glucose, protein and mineral metabolism (Palme *et al.* 2005). Cortisol samples are best taken from urine, faeces or hair to reflect longer periods of hypothalamic-pituitary-adrenocortical activity (Davenport *et al*. 2006). Richardson *et al*. (2004) reported that low-RFI steers compared to high-RFI steers had 43% of the blood cortisol concentration following stress. Nutrients may be directed to muscle growth at the expense of the immune system in fast-growing steers (Rauw *et al*. 1998), which might result in poorer feed efficiency (Klasing and Leshchinsky 2000) in the event of ill-health.

Herd and Arthur (2009) suggested that variation in RFI was associated with feed intake, digestion of feed, metabolism (i.e. anabolism and catabolism associated with and including variation in body composition), physical activity and thermoregulation. Studies on Angus steers following divergent selection for RFI estimated that heat production from metabolic processes, body composition and physical activity explained 73% of the variation in RFI. The proportions of variation in RFI that these processes explain are protein turnover, tissue metabolism and stress (37%), digestibility (10%), heat increment and fermentation (9%), physical activity (9%), body composition (5%) and feeding patterns (2%). Earlier studies had shown many hundred genes to be associated with differences in RFI, which is not surprising given the diversity of physiological processes involved.

RFI is usually measured in cattle fed *ad libitum* grain over 70 days. Young cattle with low RFI are likely to grow to become more feed-efficient adults when feed is available *ad libitum*, but Herd *et al*. (2006) suggested an interaction with level of nutrition such that this advantage may be reduced under conditions of restricted feed availability Subsequent work (Herd *et al*. 2011) confirmed that heifers superior for RFI at a young age were superior in efficiency as cows on medium-quality pasture or on unrestricted feeding. However, these advantages were not apparent during restricted feeding. EBVs for RFI post-weaning and RFI-feedlot were associated with improved cow efficiency on pasture and unrestricted feeding but not with improvement in efficiency at the restricted feeding levels typical for much of the year in pasture-based production systems. Thus the standard RFI measure appears of limited use for breeding in pasture-based systems, especially when stocking rate is optimised for production per hectare.

Herd *et al*. (2011) fed heifers from the Trangie RFI selection lines at levels that were close to maintenance or *ad libitum*. They found no difference between the lines when feed was restricted but at the higher feeding level there was more variation between animals. High-RFI (inefficient) heifers ate more, and this additional intake was associated with increased fatness. Herd and Pitchford's (2011) literature review confirmed that 1) selection for RFI is associated with phenotypic and genetic changes in body composition, and 2) under restricted feeding, there is limited variation in RFI. So there is a failure to actually improve the basal metabolism of cattle using current RFI measures.

A meta-analysis of 39 scientific publications on growing cattle (Berry and Crowley 2013) estimated a pooled heritability for RFI and feed conversion efficiency of 0.33 ± 0.01 (range 0.07–0.62) and 0.23 ± 0.01 (range 0.06–0.46), respectively. Heritability estimates for feed efficiency in cows were lower; a meta-analysis of 11 estimates revealed heritability estimates for gross feed efficiency and RFI of only 0.06 ± 0.010 and 0.04 ± 0.008, respectively.

Measuring intake of pasture feed by individual animals is a challenge. Dove (2009) outlined the problems associated with various methods and suggested that further work was needed to improve estimates of diet composition/intake using indigestible plant markers. Individual animals can be fed with a known amount of supplement containing plant wax markers to enable the estimation of diet composition and intake (Elwert and Dove 2005; Charmley and Dove 2007). Use of faecal NIRS measurements with calibration equations between faecal NIRS spectral data and known intake allow prediction of intake from faecal samples from other animals (Dixon and Coates 2009). Dove (2009) suggested that, while both NIRS and alkanes have been usefully employed to estimate intake, there is scope to use them together to improve intake estimates, provided the assumptions and limitations of each approach are recognised. NIRS spectral data are for individual animals whereas data treatment (e.g. partial least-squares regression) 'averages' the information, so data are not truly individual. Calibration equations may also be situation-specific. A system to measure pasture feed intake by animals self-dosing with wax-labelled supplement from a purpose-built bin (patent pending) was being developed by Proway Livestock and Sapien Technology (Cottle and Romero 2013).

Concentration of insulin-like growth factor-1 (IGF-1) in plasma is an indirect measure of RFI (Johnston *et al*. 2002) but the direction of the correlation is reversed in mature animals (Wood *et al*. 2004; Herd *et al*. 2004). Therefore, at best, the approach may be used to screen animals to go on for further RFI or pasture intake assessments. Barwick *et al*. (2009) found that population-specific understandings of trait relationships and trait differences between measurement times are needed if indirect or indicator traits are to be used to estimate RFI in Brahman and tropical composite feedlot cattle.

Genomics

Nkrumah *et al*. (2005) reported that polymorphisms in the coding regions of the leptin gene (a hormone secreted predominantly by white adipocytes acting as a lipostatic signal regulating whole-body energy metabolism) in cattle showed considerable associations with feed intake. They found associations between single nucleotide polymorphism (SNPs) in the 5′ untranslated promoter region of the bovine leptin gene with growth, bodyweight, feed intake, feeding behaviour and carcass merit in hybrid cattle. Animals with the TT genotype of a less frequent cytosine/thymine (C/T) substitution showed significantly higher feed intake, growth rate, metabolic BW and liveweight at slaughter. Animals with the GG genotype of a more frequent cytosine/guanine (C/G) substitution also had higher feed intake, growth rate and BW. Nkrumah *et al*. (2005) acknowledged that further efforts were required to validate these findings in other cattle populations. Lanna (2009) reported that a large multi-institutional project was in place to validate existing and future molecular markers in typical Brazilian Nellore beef production systems.

The traditional method to identify genes and genetic markers affecting a trait such as RFI is to identify quantitative trait loci (QTL) in the genome, followed by fine mapping and positional cloning. Barendse *et al*. (2007) conducted a whole-genome association study and identified many SNPs throughout the bovine genome with effects on RFI. A primary genome scan for RFI QTL has been demonstrated (Nkrumah *et al*. 2005, 2007a, b) and the several identified cattle chromosomes with RFI QTL (BTA2, 5, 10, 20 and 29) have been fine-mapped to even smaller confidence intervals (Moore *et al*. 2006). Sherman *et al*. (2008, 2009) fine-mapped QTLs for FCR and RFI using 2194 markers on 24 autosomes in 20 half-sib families. Nineteen chromosomes contained RFI QTL significant at the chromosome level. Some chromosomes contained FCR QTL but not RFI QTL, but all DMI QTL were on chromosomes where RFI QTL were detected. The most significant QTL for RFI was located on *Bos taurus* (BTA) chromosome 3, for FCR on BTA 24 and for DMI on BTA 7. The RFI QTL that showed the most consistent results with previous RFI QTL mapping studies were on BTA 1, 7, 18, and 19. Sherman *et al*. (2008, 2009) found six SNPs to have effects on RFI; the largest single SNP allele substitution effect was -0.25 kg/day located on BTA2. The combined effects of the SNPs found significant in this experiment explained 6.9% of the phenotypic variation of RFI. Sherman *et al*. (2010) later studied 2633 SNPs across the 29 bovine autosomes in 464 steers. They acknowledged that SNPs need to be verified in independent populations of cattle as there are so few actual gene markers.

Al-Husseini *et al*. (2013) reported that hormonal growth promotants (HGP), that improve FCR and growth rates of cattle by modifying protein turnover rates, did not affect RFI or the expression of eight RFI-associated genes: AHSG, GHR, GSTM1, INHBA, PCDH19, S100A10, SERPINI2 and SOD3. HGP treatment increased ADG by 20%, improved FCR by 18% and increased rib eye-muscle area by 7.5%, presumably by its known action in the protein turnover mechanism, but this did not seem to be one of the regulators of RFI.

The identification of QTL and SNPs is a starting point to identify genes affecting feed intake and efficiency for use in marker-assisted selection and management. Despite some patents being filed for QTLs (Pitchford *et al*. 2006) and SNPs (Barendse and Reverter-Gomez 2006; Hayes *et al*. 2006; Moore *et al*. 2008) related to RFI in cattle, there was little commercial use of SNPs by 2013 for this purpose. Taylor *et al*. (2012) noted that issues limiting the efficiency of genomic selection in beef cattle were associated with the assembly of sufficiently large SNP training populations, the need for periodic retraining and delivering the technology at the required price point.

Reduction in methane production

Methanogenic microbes combine carbon dioxide and hydrogen gas in the rumen to produce methane that is belched out. This results in a loss of digestible feed energy to the animal, lowering its feed use efficiency, and the release of this greenhouse gas to the atmosphere (Cottle *et al*. 2011). Methane is expensive and difficult to measure directly in individual cattle. Technologies such as Greenfeed bins (Zimmerman 2012) are expensive and likely to be mainly used for research.

Indirect selection traits that are most likely to be of use for reducing methane are those associated with feed intake and the efficiency of feed use. Methane production and feed intake have high positive phenotypic correlations (Howden *et al*. 1994; Williams and Wright 2005). The phenotypic correlation between traits is the best estimate of the genotypic correlation if the latter are unknown. These phenotypic correlations form the basis of current Australian carbon accounting methods.

$$\text{Methane production (kg)} = 0.0187 \times \text{DMI (kg)} - 0.0003,\ r^2 = 0.87$$

O'Hara *et al.* (2003) noted that the relationship between methane emission (g/day) and DMI is characterised by high variability between animals. They suggested that, for efficient animal production and reduced methane emission, it is best to feed animals well above maintenance. However, cattle which produce more beef per unit DMI will produce less methane per kg product at any intake level.

Between-sire differences in feed intake have been reported for large-scale crude assessments of pasture intake by ewes (Lee 2000) but there have been no such reported studies in cattle. If selection for feed efficiency or intake is the most likely avenue for reducing methane production, an economic value for feed intake is required to reflect differences in the cost of pasture in different production systems (Farquharson 1993). As feed costs are substantial for most classes of livestock, including young growing animals, improvement of feed efficiency should be a major consideration in most breeding programs (Kennedy *et al.* 1993).

Nkrumah *et al.* (2006) found that RFI was correlated with methane production (MPR) and energy lost as methane (r = 0.44). Methane production in low-RFI animals was 28% lower than that of high-RFI animals, and 24% lower than that of medium-RFI animals. Hegarty *et al.* (2007) studied 76 Angus steers chosen from breeding lines divergently selected for RFI, to quantify the relationship between RFI and the daily rate of MPR. The EBV for RFI (RFI_{EBV}) for each steer on a barley-based diet was calculated from 70-day RFI tests conducted on its parents. Animals expressing lower RFI had lower daily MPR but the phenotypic correlation, while statistically significant, was only 0.35:

$$\text{MPR} = 13.3 \times \text{RFI}_{15\text{d}} + 179,\ r^2 = 0.12$$

The change in daily emission of 13.3 g methane/RFI_{EBV} (kg/day) was between that predicted on the basis of intake reduction alone (18 g/day/kg DMI) and that predicted by a model incorporating steer MWT and intake level relative to maintenance (5 g/day/kg DMI). The low-$\text{RFI}_{15\text{d}}$ group had a lower methane cost of growth (by 41.2 g methane/kg of ADG) compared to the high-RFI group. Although this suggested selection against RFI would reduce MPR, RFI explained only a small proportion of MPR variance. Hegarty *et al.* (2007) suggested that there is a high genotype × nutrition interaction. This could make the use of RFI to reduce MPR difficult in Breedplan and less successful on high-energy (feedlot) diets. Hegarty (2009) reported MPR of Angus steers from breeding lines divergently selected for RFI. The work has typically been unable to show a significant reduction in MPR associated with decreasing RFI. This was considered to be partly due to the high-energy (feedlot) diet usually used. Prediction equations show that the effect on MPR from reducing intake of this diet by 1 kg/day is far less than would be achieved on diets of lower ME concentration. In the course of studying the methane–RFI relationship, individual animals were identified as producing more methane than predicted (HMP) or less methane than predicted (LMP) from equations given in Blaxter and Clapperton (1965). Clear evidence of sire differences (Herd *et al.* 2011) in methane yield indicate that direct selection offers a means of reducing it and methane/unit animal product. Cottle *et al.* (2011) reviewed selecting for RFI, as well as nutritional and management options for methane mitigation.

Alford *et al.* (2006) modelled the expected reduction in methane emissions from the Australian beef herd resulting from using bulls identified as being more feed-efficient (as a result of having a lower RFI, both in a single herd in southern Australia and in the national herd). A gene flow model was developed to simulate the spread of improved RFI genes through a breeding herd over 25 years, from 2002–26. Based on the estimated gene flow, the voluntary feed intakes were revised annually for all beef classes using parameters taken from the Australian National Greenhouse Gas Inventory (DCC 2008). Changes in emissions (kg methane/head/year) associated with the reduction in feed intake were then calculated using national carbon accounting procedures. Annual enteric methane emissions from both the individual and national herd were calculated by multiplying the livestock numbers in each beef class by the revised estimates of emissions per animal. For an individual adopting herd, the annual methane abatement in year 25 of selection was 15.9% lower than in year 1. For the national herd, differential lags and limits to adoption were assumed for northern and southern Australia. The cumulative reduction in national emissions was 568 100 t of methane over 25 years, with annual emissions in year 25 being 3.1% lower than in year 1. They concluded that selection for reduced RFI should be worthwhile.

Desjardins *et al.* (2012) studied the carbon footprint of beef cattle in Canada, the USA, EU, Australia and Brazil. The values ranged between 8 kg and 22 kg CO_2-e per kg of

LW depending on the type of farming system, location, year, type of management practices, allocation method (Wiedemann 2012) and the boundaries used in the studies. Substantial reductions were observed for most of these countries from 1981 to 2006. For instance, in Canada the mean carbon footprint of beef cattle at the exit gate of the farm decreased from 18.2 kg CO_2e per kg LW in 1981 to 9.5 kg CO_2e per kg LW in 2006, mainly because of improved genetics, better diets and more sustainable land management practices. The cattle carbon footprint needs to be reported in kg of CO_2e per kg of product, as products differ (Desjardins *et al.* 2012). For example, in Canada in 2006, on a mass basis, the carbon footprint of cattle by-products at the exit gate of the slaughterhouse was 12.9 kg CO_2e per kg of product. Based on an economic allocation, the carbon footprints of meat (primal cuts), hide, offal and fat, bones and other products for rendering were 19.6, 12.3, 7 and 2 kg CO_2e per kg of product, respectively.

CATTLE BREEDING AND MANAGEMENT

An objective of breeding programs is to increase the efficiency of production and, irrespective of how efficiency is defined, the efficiency of nutrient utilisation will form a major component of the breeding program objective (Pitchford 2004; Chapter 17).

Economic objectives in beef cattle breeding include improved rate of reproduction, efficiency of lean growth and quality of lean cuts because these are the biological components of cost per unit of meat value produced (Dickerson *et al.* 1974). Thus, evaluation of selection criteria traits for improving efficiency of beef production should include their effects on the carcass composition, meat quality and optimum economic weight at slaughter of calves and the mature size, milk production and calving difficulties of cows.

Cundiff *et al.* (1993) argued that a more productive way to frame the breeding efficiency question is to ask which cattle are most efficient in a specific environment and production system, and that defining optimum efficiency in the cattle business was complicated. Overall efficiency of a cattle production system is a combination of biological efficiency(feed consumed to beef produced) and economic efficiency (dollars spent to dollars returned). Maximum biological and economic efficiency, either per head or per hectare, are related but may not occur at the same production levels. Increasing biological efficiency can militate against economic efficiency if the end products' qualities do not match customers' needs (Chapter 3). Thus producers need to understand and manage the genetic potential of cattle and their environment and make decisions about when and what product to market.

Cow size

What is the breeding objective in regard to the size and LW of cows? This will depend on the production system, environment and targeted market, for reasons outlined below.

Dickerson (1970) stated that efficient cow herds exhibit early sexual maturity, high rates of reproduction, low rates of dystocia, longevity, minimum maintenance energy requirements, and the ability to convert forage into weight of weaned calves. To maximise efficiency in the cow–calf context, the objective is lean growth and earlier sexual maturity with minimum increase in mature weight (Cundiff *et al.* 1993). For a grazing cow, the ability to reproduce is by far the most important contributor towards efficiency (Chapter 14), and the ability to reproduce in a given feed environment is related to a cow's mature size.

Cundiff *et al.* (1993) reported that in comparison to cattle in extensive conditions, cattle that excel in the production of retail product typically produce heavier birth weights, reach puberty at older ages, have lower propensities to marble and have higher maintenance requirements due to heavier mature weights and greater visceral mass. Continental breeds of cattle with these characteristics were introduced into Australia and the USA in the 1970s. Their importation was a reaction to both the 'green revolution' of the 1960s, which reduced the cost per unit feed in the feedlot industry, and to industry-changing technologies which favoured heavier slaughter weights for processors (Ferrell and Jenkins 2006). Essentially, a market was developed to suit cattle with the genetic potential to take full advantage of low-cost feed. The US packing industry (Chapter 5) continues to reward large-framed cattle yielding the most meat possible in the assembly line. Efficiency in the feedlot and packing plants is the driving force behind the US market signals to select for increased growth traits and carcass weight. Selecting for increased weaning weight leads to an increase in mature cow size, which, depending on feed availability, may or may not be efficient in a grazing environment (Long *et al.* 1975; Kelly *et al.* 2010). Producers can mitigate the increased cost of larger cows by lowering stocking rates and/or using feed supplements if they are inexpensive and readily available. Cow size and feed availability dictate herd size; the optimal herd size will vary with the cost structure of specific production systems.

Economic efficiency varies with different production systems. The goal at pasture is to have the highest percentage of calf crop at the heaviest weight without causing dystocia, and therefore maximum total weight of calves, with the minimum amount of investment and costs. In a feedlot, the goal is to produce the most beef possible in order to profit at a margin above feed costs. Biological traits supporting efficient use of pasture are markedly different from traits supporting efficient use of harvested concentrates (Notter 2002). Because the cost structures are different, the most efficient grazing animal may not be the best animal in the feedlot and vice versa (Chapters 11, 17).

Thus biological and economic efficiency are not always positively correlated due to the segmentation of the beef cattle industry into grazing cow/calf herds and backgrounding/stocker herds, finishing (grass and feedlot) systems and processing. In grazing systems (Chapter 15), cattle must be efficient in what is often a limited-energy, forage-based, high investment per unit business. Feedlot (Chapter 11) cattle must be efficient in a high-energy, grain-based, low investment per unit, margin-based business. The processing sector (Chapter 2) has the lowest investment per animal unit and is also a margin-based business where throughput is the primary driver. However, there are increasing numbers of higher-value branded products, so quality is also important.

Only a small number of cow–calf producers maintain ownership of their cattle through the backgrounding, yearling or feeding segments (Melton 1995; PWC 2011). The price received for weaned calves is affected by LW, lot size, uniformity, health, horns, condition, gut fill, breed, muscling and frame size. Feeder cattle buyers prefer larger-framed, heavier-muscled cattle (Schroeder *et al.* 1988; Andrews and Littler 2007). A cow–calf producer who selects smaller-framed cattle hoping that they have lower maintenance requirements and are more biologically efficient may find its stock later discounted in the marketplace. This may decrease the economic efficiency of the operation if the higher stocking rate and number of sale animals do not compensate for the lower price per head.

In an analysis of a 165 000 cow database, Cundiff *et al.* (1993) not surprisingly found that bigger cows weaned bigger calves. The authors concluded that the additional energy requirements of a larger cow were more than paid for by the additional weight of her calf, in the context of the US market. The objective is to maximise calf growth and minimise cow feed requirements, and cow size varies depending on the relative economic values of these traits. As stated in Chapter 17, selection should be based on a balanced objective. An index is the best method to achieve this but some modelling of trait relationships should aid understanding.

Metabolic weight versus liveweight

An elephant weighs ~220 000 times as much as a mouse, but requires only ~10 000 times the maintenance feed energy. This is because of the geometric relationship between body surface area and volume. Metabolic bodyweight was first calculated as liveweight$^{0.75}$ by Kleiber (1932) based upon the idea that metabolic energy was related to measurements of heat generation and loss. Kleiber (1961) and Brody (1945) showed that fasting heat production (FHP) was related closely to $W^{0.75}$ and $W^{0.73}$, respectively, when sex differences and means of species varying more than 1000-fold in average LW were analysed. This relationship has been used in National Research Council and Agricultural Research Council publications. However, there is some debate about whether 0.75 is the correct allometric exponent to use (Freer *et al.* 2007). Thonney *et al.* (1976) argued that animal responses should be corrected for W^b or logW, where the model logFHP = $b_0 + b_1$ (logW) is fitted to species-sex subclass data.

Taylor (1987) pointed out that, when selecting for improved feed efficiency, it is important for a producer not to waste 75% of the selection pressure by inadvertently selecting for changes in mature body size. Essentially, the bigger the animal, the more efficiently it uses energy. For example, 100 600 kg cows require the same amount of maintenance food energy as 115 500 kg cows because a 600 kg cow weighs 20% more than a 500 kg cow but its feed requirements are only 15% higher. However, a calf from a 600 kg cow is likely to be 5% later maturing than one from a 500 kg cow, so systems are complex and, as noted earlier, need to be modelled. Knowing equivalent herd sizes based on Kleiber's Theory allows an approximate comparison of the feed efficiency of different sizes of cattle. However, a biological understanding of how maintenance energy varies with size is not useful unless paired with an economic understanding of how herd size affects profitability (Cundiff *et al.* 1993).

If herd size is adjusted correctly, switching from larger to smaller cattle will not increase total fixed costs or feed costs but it will increase other variable costs, depreciation costs and investment costs in terms of cattle inventory due to running more cattle. Therefore, the gross income generated by selling a greater number of lighter calves must outweigh these additional variable, depreciation and investment costs in order to justify the decrease in cow size. Alternatively, switching from smaller to larger cattle will decrease variable, depreciation and investment costs, with no change to fixed or feed costs. However, producers in highly variable feed environments may benefit from a greater number of smaller cattle because of the economic risk associated with low reproduction rates of larger cows if supplemental feed is unavailable or expensive. These types of comparisons can be made using spreadsheets. No one breed or size of cattle fits all systems in terms of productivity and efficiency, so careful analysis of the environment, market and goals of systems is needed. The optimal herd size for any farm depends on rainfall, infrastructure, investment and labour. Herd size can be increased by reducing mature cow size to a certain weight, which will vary in different systems, without increasing feed and fixed costs but, as noted, this increases investment and variable costs.

Growth rates and maturity

The relationships reported by Klieber and Brody are also useful in studying the effect of growth on efficiency of production. A growth curve for this purpose, with biologically meaningful parameters and that is relatively easy to fit following modification of the Gompertz model, was developed by Pitchford *et al.* (1993):

$$W_t = Ae^{(\ln\frac{B}{A})e^{-kt}}$$

W_t is the animal weight at time t, A is mature or asymptotic weight, B is birth or initial weight, k is the maturity factor and t is age or time. Birth weight of cattle is commonly ~6% of their mature weight; the rate of maturity is a time function and is related to $A^{0.25}$. Relating this to mice and elephants, an elephant would be expected to live $220\,000^{0.25} = 22$ times longer than a mouse. Thus, the equation can be simplified based on these relationships:

$$W_t = Ae^{(\ln 0.06)e^{-kA^{-0.25}t}}$$

This simplifies to be a two-parameter function (Fig. 18.12) of mature weight and rate of maturity (which is also a function of mature weight):

$$W_t = Ae^{-2.8e^{-0.028A^{-0.25}t}}$$

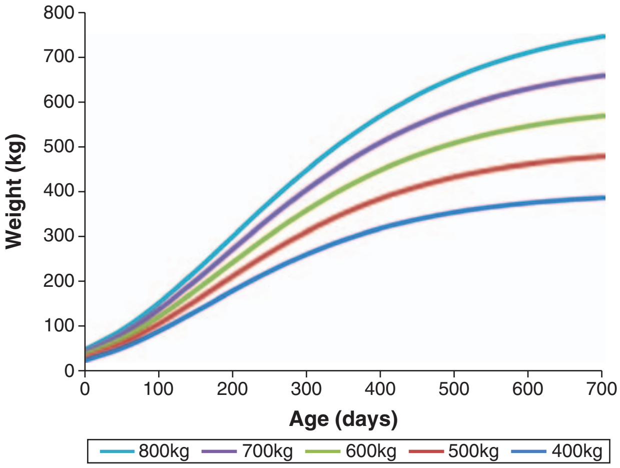


Figure 18.12: Growth of heifers for five different mature weight cows (400–800 kg) assuming maturity factor $k = 0.028$. k is lower on low-quality feed.

For the range of cow mature weights (400–800 kg), weaning weights at 200 days of age range from 180–301 kg. For a measure of breeder herd efficiency, W_t could be weaning weight (e.g. at 200 days) and, if mature cow feed intake is related to $A^{0.75}$, then $W_t/A^{0.75}$ could be a ratio worth examining to compare systems, as it is a crude measure of weaning weight produced per unit of cow feed intake. A plot of this ratio versus age of calf is presented in Fig. 18.12, demonstrating that the ratio is basically a constant across cow sizes when calves are marketed at young ages. Specifically, cow size affects system efficiency only when calves are marketed older than one year of age (Fig. 18.13).

The genetic correlation between weight at a young age and mature cow weight is positive. Selection for increased growth leads to bigger cows that eat more and are slightly later maturing. However, the genetic correlation is only

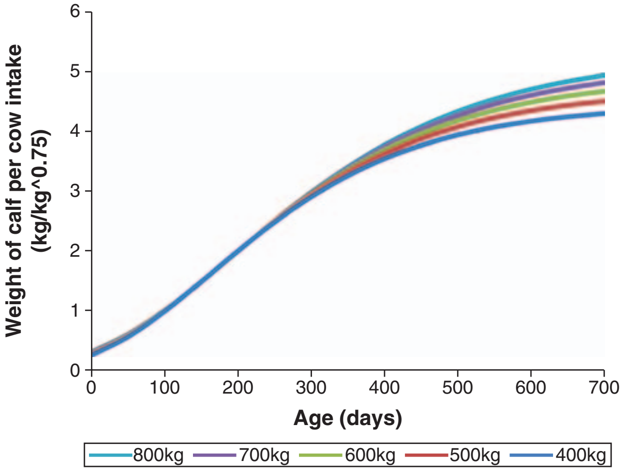


Figure 18.13: Expected relationship between efficiency defined as weight of calf per unit cow metabolic weight and offspring age.

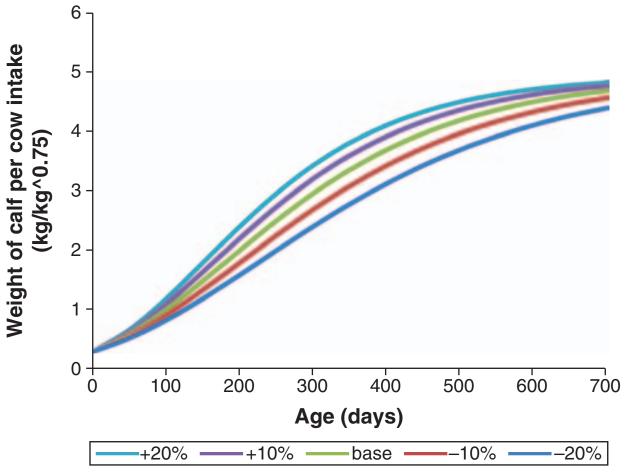


Figure 18.14: Expected effect of changes (–20% to +20%) in rate of maturity (base *k* = 0.028) and breeder herd efficiency versus age of turnoff.

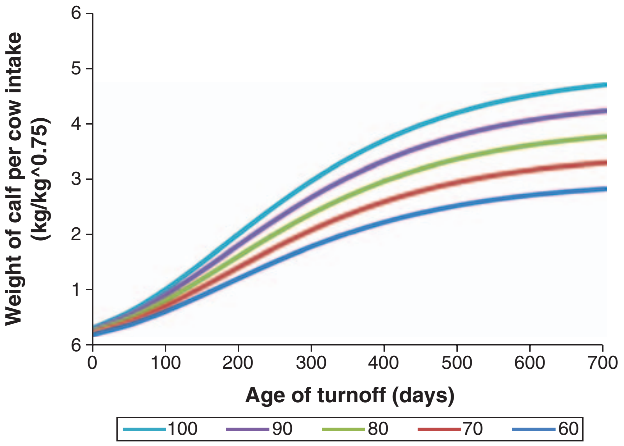


Figure 18.15: Expected effect of changes in calf weaning rate (60–100%) on breeder herd efficiency, assuming dry cows are retained.

~0.5 (Robinson 1996) so if young growth and mature weights are both recorded there is opportunity to select for changes in rate of maturity. This leads to improvements in theoretical breeder herd efficiency, where calves are marketed at young ages. Expected effect on breeder herd efficiency with changes (–20% to +20%) in maturation rate with variable age of calf marketing (Fig. 18.14) suggest that breeder herd efficiency is related to early maturity when calves are marketed at young ages.

While this is true biologically, the reality of production systems is that market specifications affect price received; as noted earlier, profitability is not the same as biological efficiency. Furthermore, as stated above, supply-chain profitability may not be the same as that in individual sectors. Figure 18.12 has growth curves for heifers of different mature size. With weight for age, bigger is always better. However, for reaching market specifications, how long each beast takes to reach a specific weight is more important. The biggest range is to reach 350 kg, where the 400 kg and 800 kg mature weight genotypes take 486 and only 232 days respectively. Being more extreme, the 400 kg and 500 kg mature weight cows never reach over 500 kg live. Even without the extreme example, reaching heavy-weight market endpoints is much faster for large mature weight cattle. The post-weaning time taken to meet market specification is the biggest driver of profitability both biologically and economically, along with reproductive rate (Fig. 18.15) because additional calves dilute the fixed cost of maintaining the cow.

To summarise, small cows may be of equal efficiency for producing carcasses for the domestic market, but large cows are required to produce steers able to reach export specifications profitably (Fig. 18.13). Selection for increased rate of maturity by selecting for high growth at young ages relative to weights at later ages, so-called ‘curve benders’, should improve breeder herd efficiency (Fig. 18.14) and not have negative consequences for feeder steers. In the industry, appropriate weightings on traits measured in Breedplan are achieved by using a formal breeding objective (Barwick and Henzell 2005; Chapter 17).

Calf weight/cow weight as a measure of productivity

Simple efficiency ratios can be used (Figs 18.13, 18.14) for modelling systems as above, but the calf or weaning weight/cow weight ratio is not appropriate for the purposes of animal selection (Dinkel and Brown 1978; Cartwright 1979). One reason is that using ratios as a selection criterion results in the confounding of direct and maternal genetic effects on phenotypes (MacNeil 2005). Assumptions of feed intake may not be accurate (Cartwright 1979) and there can be differences in calf age, sex and other variables. The ratio also dilutes the impact of reproduction if dry cows are not included: a 25 kg difference in weaning weight is small compared to having a 150 kg calf versus no calf. This is optimised in Breedplan selection indices by using appropriate economic weights for weaning weight and reproduction (Barwick and Henzell 2005; Chapter 17). Cows with heavier calves have higher intakes even when dry. Cows producing more milk may be less likely to re-breed. For the majority of cow–calf producers, the most efficient cow is the one that calves annually and early in the season and that produces a heavy calf due to age, milk supply (200 days maternal) and inherited growth ‘potential’ (200 days direct), with the growth and carcass characteristics valued most in the marketplace.

Though it does not reflect individual cow efficiency, the ratio of total weight weaned divided by number of cows exposed to bulls is a reasonable measure of productivity for the entire herd. This ratio recognises the most important maternal trait for efficiency – reproduction – without confounding variables. Increasing this ratio without increasing input costs should result in increased net profit.

Optimising breeding systems

Crossbreeding programs can be an ideal way to quickly increase efficiency (Chapter 17). A terminal sire bred to a crossbred female will wean ~28% more beef per exposed female than a purebred (Kinghorn 2000; Field and Taylor 2003). Cuthbertson *et al*. (1990) reported that a large terminal sire breed (e.g. Charolais) crossed to a small-frame dairy-cross cow (e.g. Hereford/Jersey) increased efficiency of production by 40% compared to purebred Herefords. Crossbreeding systems that exploit heterosis, match feed resources and climates and meet market targets provide an effective means of breeding for productivity (Chapter 17). The relatively simplistic measure of efficiency used above can be used to demonstrate the effect of crossbreeding where there are varying differences between sire and dam breeds in mature weight (Fig. 18.16). Since the effect of crossbreeding is to increase calf output relative to cow feed intake, the effect is similar to that of weaning rate.

Market end point affects the efficiency of a system. Increased milk potential is most beneficial when calves are sold at weaning and maximum pre-weaning growth is rewarded. If weaners are retained, the calf’s own growth potential has a longer period of time to capture profit for the breeder.

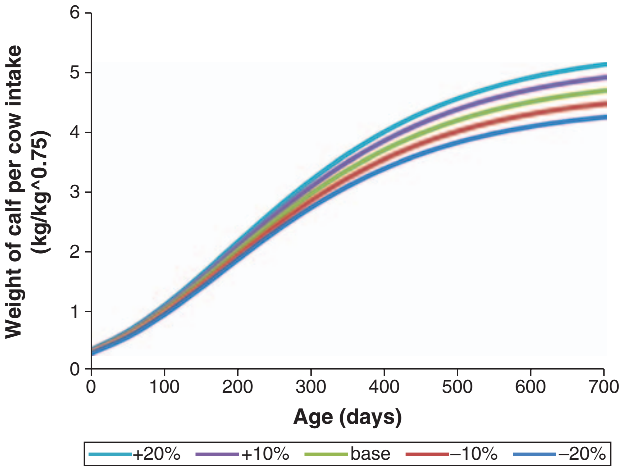


Figure 18.16: Effect of crossbreeding on efficiency using sire breeds of varying mature weights relative to dam breed (-20% to +20%), assuming the only effect is on growth.

Price and availability of feed varies between regions. Environments can be categorised by levels of feed and stress (e.g. temperature, parasites, disease, altitude). The efficiency of *Bos indicus* cattle compared to *Bos taurus* in tropical and subtropical environments is partly due to their heat tolerance (Chapters 9, 14).

Nutrition by genotype effects on breeder herd efficiency

Efficiency results from the Beef CRC Maternal Productivity project are given in Table 18.6. The project included four Angus genetic groups: high-fat were heifers sourced from industry with EBVs in the top 5% of the breed for rib fat, low-fat were the bottom 5%, and three generations of selection for high RFI or low RFI. These were raised for three parities on either low nutrition or 20% more, termed high nutrition, based on differences in stocking rate.

Nutrition level had a bigger effect than genetic line, with productivity levels on low nutrition (4.5–4.8 g/MJ) being 10–17% greater than on high nutrition (4.1–4.2 g/MJ). When cow weight gain was accounted for, the

Table 18.6: Effects (mean ± standard error) of genotype and nutrition on maternal productivity

	High-nutrition		Low-nutrition		High-nutrition		Low-nutrition	
Genotype	High-fat	Low-fat	High-fat	Low-fat	High-RFI	Low-RFI	High-RFI	Low-RFI
Energy intake (MJ/day)	160±3	154±3	125±3	127±3	155±4	149±5	127±5	117±5
Weight of calf weaned (kg)	241±3	231±3	217±3	207±3	227±4	217±4	205±5	196±5
Weight gain of cows (kg)	77±5	89±5	57±5	63±5	58±7	75±7	43±8	50±8
Maternal productivity (g calf/MJ)	4.2±0.1	4.2±0.1	4.8±0.1	4.5±0.1	4.2±0.2	4.1±0.2	4.5±0.2	4.8±0.2
Maternal productivity (g cow+calf/MJ)	5.6±0.2	5.8±0.2	6.1±0.2	5.9±0.2	5.2±0.3	5.5±0.3	5.5±0.3	6.0±0.3

difference between nutrition treatments was smaller (5–7%). The low-nutrition treatment was achieved with high stocking rate and would be associated with greater risk of low profitability during dry years.

While there were differences between genetic lines in body composition, calf growth and feed intake, on high nutrition there were negligible differences between lines in maternal productivity (calf output per energy input). However, under low nutrition, the high-fat line had a 7% greater productivity when considering the calf only, and 3% when cow gain was included. This was primarily due to the greater number of calves weaned by the high-fat line. The fat lines were larger cattle than the RFI lines, but the average productivity was similar. These results support the theoretical results above that cow size and even composition has little impact on maternal productivity except through differences in weaning rate. While not statistically significant, selection for efficiency (low-RFI) did result in 7% greater productivity. The result held up when cow gain was accounted for and even when the composition of gain was accounted for (not presented). In addition to the productivity differences, the high-fat and high-RFI lines required less supplementary feed than their low counterparts because they were fatter. This is likely to affect profitability.

FUTURE DIRECTIONS AND CHALLENGES

It has been demonstrated that factors affecting production efficiency depend on the age at which calves are marketed and that different sectors of the supply chain (breeder, backgrounder, finisher, processor) have different profit drivers. Thus, different traits are considered when defining efficiency in the various sectors and these need to be accounted for when developing selection indices which aim to improve supply chain efficiency and therefore profitability.

Breeders need to measure as many traits as possible to prevent genetic change in undesired directions due to genetic correlations (Chapter 17). The most obvious is early growth relative to calving ease and mature weight. Selection for market traits (i.e. growth, yield, marbling, tenderness) are important as increasing the value of output relative to inputs improves profitability. There also needs to be strategic use of supplementary feeding and/or stock trading to manage the resources (Chapter 20).

Reproduction (Chapter 14) is a key to improving biological efficiency and profitability, and there is a need for tools to help do this in young bulls. This is where genomics is likely to have its greatest impact because reproductive traits have high value and can be sex-limited.

There is no practical method for selecting for low-maintenance feed requirements of cows, despite feed costs accounting for the majority of input costs. However, selection for low post-weaning RFI has resulted in cattle that are more efficient as steers in the feedlot (Herd *et al*. 2013) and cows on pasture. The low-RFI cattle are also leaner, which may be a positive or negative depending on feed availability. Health (Chapter 13) and nutrition (Chapters 15 and 16) issues can also have large impacts on production efficiency.

REFERENCES

ABARE (2008) *Productivity Growth: Australian Commodities*. Vol. 15, No. 1, March 2008. Australian Bureau of Agricultural and Resource Economics, Canberra.

ARC (1980) *The Nutritional Requirements of Ruminant Livestock*. Agricultural Research Council, Commonwealth Agricultural Bureaux, Slough.

Al-Husseini W, Gondro C, Quinn K, Cafe L, Herd R, Gibson J, Greenwood PL, Chen Y (2013) Hormonal growth implants affect feed efficiency and expression of residual feed intake-associated genes in beef cattle. *Animal Production Science* **53**. doi.org/10.1071/AN12398.

Alexander GI (1965) Management aspects of beef cattle production. *Australian Veterinary Journal* **41**, 61–65.

Alford AR, Hegarty RS, Parnell PF, Cacho OJ, Herd RM, Griffith GR (2006) The impact of breeding to reduce residual feed intake on enteric methane emissions from the Australian beef industry. *Australian Journal of Experimental Agriculture* **46**, 813–820. doi:10.1071/EA05300.

Andrews T, Littler B (2007) *Market Specifications for Beef Cattle*. Primefact 621. <http://www.dpi.nsw.gov.au/data/assets/pdf_file/0005/148415/Market-specifications-for-beef-cattle.pdf>.

Arango JA, Van Vleck LD (2002) Size of beef cows: early ideas, new developments. *Genetics and Molecular Research* **1**, 51–63.

Archer JA, Bergh L (2000) Duration of performance tests for growth rate, feed intake and feed efficiency in four biological types of beef cattle. *Livestock Production Science* **65**, 47–55. doi:10.1016/S0301-6226(99)00181-5.

Archer JA, Arthur PF, Herd RM, Parnell PF, Pitchford WS (1997) Optimum post weaning test for measurement of growth rate, feed intake and feed efficiency in British breed cattle. *Journal of Animal Science* **75**, 2024–2032.

Archer JA, Arthur PF, Herd RM, Richardson EC (1998) Genetic variation in feed efficiency and its component traits. In *Proceedings of the 6th World Congress on Genetics Applied to Livestock Production* **25**, 81–84. Armidale, NSW.

Archer JA, Richardson EC, Herd RM, Arthur PF (1999) Potential for selection to improve efficiency of feed use in beef cattle: a review. *Australian Journal of Agricultural Research* **50**, 147–161. doi:10.1071/A98075.

Archer JA, Reverter A, Herd RM (2002) Genetic variation in feed intake and efficiency of mature beef cows and relationships with postweaning measurements. In *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production* **31**, 221–224. Institut Nacional de la Recherche Agronomique, Montpellier, France.

Arthur PF, Herd RM (2005) Efficiency of feed utilization by livestock: implications and benefits of genetic improvement. *Canadian Journal of Animal Science* **85**, 281–290. doi:10.4141/A04-062.

Arthur PF, Archer JA, Johnston DJ, Herd RM, Richardson EC, Parnell PF (2001) Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. *Journal of Animal Science* **79**, 2805–2811.

Arthur PF, Archer JA, Herd RM (2004) Feed intake and efficiency in beef cattle: overview of recent Australian research and challenges for the future. *Australian Journal of Experimental Agriculture* **44**, 361–369. doi:10.1071/EA02162.

Baldwin RL, Smith NE, Taylor J, Sharp M (1980) Manipulating metabolic parameters to improve growth rate and milk secretion *Journal of Animal Science* **51**, 1416–1428.

Barendse W, Reverter-Gomez A (2006) A method for assessing traits selected from *longissimus dorsi* peak force, intramuscular fat, retail beef yield and net feed intake in bovine animals. PCT/AU2006/001044.

Barendse W, Reverter A, Bunch RJ, Harrison BE, Barris W, Thomas MB (2007) A validated whole-genome association study of efficient food conversion in cattle. *Genetics* **176**, 1893–1905. doi:10.1534/genetics.107.072637.

Barlow R (1984) Selection for growth and size in ruminants: is it time for a moratorium? In *Proceedings of the 2nd World Congress on Sheep and Beef Cattle Breeding*, Pretoria. (Eds JH Hofmeyr and EHH Meyer) pp. 421–432.

Barwick SA (2002) Costing feed in selection: reconciling some differences in approach and revisiting issues for beef cattle selection. *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production* **31**, 273–276.

Barwick SA, Henzell AL (2005) Development successes and issues for the future in deriving and applying selection indexes for beef breeding. *Australian Journal of Experimental Agriculture* **45**, 923–933. doi:10.1071/EA05068.

Barwick SA, Wolcott ML, Johnston DJ, Burrow HM, Sullivan MT (2009) Genetics of steer daily and residual feed intake in two tropical beef genotypes, and relationships among intake, body composition, growth and other post-weaning measures. *Animal Production Science* **49**, 351–366. doi:10.1071/EA08249.

Barwick S, Graser H, Jeyaruban G, Johnston D, Wolcott M (2011) Review of potential investment into recording feed efficiency in beef cattle. MLA Project B.BFG.0050. AGBU, Armidale, NSW.

Basarab JA, Price MA, Aalhus JL, Okine EK, Snelling WM, Lyle KL (2003) Residual feed intake and body composition in young growing cattle. *Canadian Journal of Animal Science* **83**, 189–204. doi:10.4141/A02-065.

Berry DP, Crowley JJ (2013) Genetics of feed efficiency in dairy and beef cattle. *Journal of Animal Science* **91**, 1594–1613. doi:10.2527/jas.2012-5862.

BetterBeef Network (2013) *Welcome to the BetterBeef Network*. <http://new.dpi.vic.gov.au/agriculture/beef-and-sheep/beef/betterbeef-network>.

Bindon BM, Jones NM (2001) Cattle supply, production systems and markets for Australian beef. *Australian Journal of Experimental Agriculture* **41**, 861–877. doi:10.1071/EA01052.

Blaxter KL, Clapperton JL (1965) Prediction of the amount of methane produced by ruminants. *British Journal of Nutrition* **19**, 511–522. doi:10.1079/BJN19650046.

Blocker A, Ibendahl G, Anderson J (2003) *Interpreting Farm Financial Ratios*. <http://www.cottoninc.com/fiber/AgriculturalDisciplines/AgriculturalEconomics/Farm-Finance/Calculating_Financial_Ratiios_for_Cotton_Farmers.pdf>.

Bravo-Ureta BE, Evenson RE (1994) Efficiency in agricultural production: the case of peasant farmers in Eastern Paraguay. *Agricultural Economics* **10**, 27–37. doi:10.1016/0169-5150(94)90037-X.

Bravo-Ureta BE, Daniel S, Lopez VHM, Maripani JF, Abdourahmane T, Rivas T (2007) Technical efficiency in farming: a meta-regression analysis. *Journal of Productivity Analysis* **27**, 57–72. doi:10.1007/s11123-006-0025-3.

Brody S (1945) *Bioenergetics and Growth*. Reinhold Publishing, New York.

Brummer B, Glauben T, Thijssen G (2002) Decomposition of productivity growth using distance function: the case of dairy farms in three European countries. *American Journal of Agricultural Economics* **84**, 628–644. doi:10.1111/1467-8276.00324.

Bunter KL, Cai W, Johnston DJ, Dekkers JCM (2010) Selection to lower residual feed intake in pigs produces a correlated response in juvenile insulin-like growth factor-I (IGF-1) concentration. *Journal of Animal Science* **88**, 1973–1981. doi:10.2527/jas.2009-2445.

Burrow HM, Gulbransen B, Johnson SK, Davis GP, Shorthose WR, Elliott RF (1991) Consequences of selection for growth and heat resistance on growth, feed conversion efficiency, commercial carcass traits and meat quality of Zebu crossbred cattle. *Australian Journal of Agricultural Research* **42**, 1373–1383. doi:10.1071/AR9911373.

Burrow HM, Johnston DJ, Barwick SA, Holroyd RG, Barendse W, Thompson JM Griffith GR, Sullivan M (2003) Relationships between carcass and beef quality and components of herd profitability in northern Australia. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **15**, 359–362.

Cartwright TC (1979) Size as a component of beef production efficiency: cow-calf production. *Journal of Animal Science* **48**, 974–980.

Charmley E, Dove H (2007) Using plant wax markers to estimate diet composition and intakes of mixed forages in sheep by feeding a known amount of alkane-labelled supplement. *Australian Journal of Agricultural Research* **58**, 1215–1225. doi:10.1071/AR07187.

Cho J, Park SC, Bevers SJ (2011) *An Economic Performance Analysis of the Beef Cow-herd Enterprise Using a Stochastic*

Frontier Function. Southern Agricultural Economics Association Annual Meeting, Corpus Christi, Texas, 6–8 February 2011. <http://ageconsearch.umn.edu/bitstream/98842/2/MainPaper.pdf>.

Coelli TJ (1995) Recent developments in frontier modeling and efficiency measurement. *Australian Journal of Agricultural Economics* **39**, 219–245. doi:10.1111/j.1467-8489.1995.tb00552.x.

Coelli TJ, Perelman S (2000) Technical efficiency of European railway: a distance function approach. *Applied Economics* **32**, 1967–1976. doi:10.1080/00036840050155896.

Cottle DJ, Romero C (2013) Improving pasture intake predictions by variable weighting of plant marker concentrations. *Animal Feed Science and Technology*. (In press). doi:10.1016/j.anifeedsci.2013.10.004

Cottle DJ, Nolan JV, Wiedemann SG (2011) Ruminant enteric methane mitigation: a review. *Animal Production Science* **51**, 491–514. doi:10.1071/AN10163.

Crews DH (2005) Genetics of efficient feed utilization and national cattle evaluation: a review. *Genetics and Molecular Research* **4**, 152–165.

Cundiff LV, Szabo S, Gregory KE, Koch RM, Dikeman ME, Crouse JD (1993) Breed comparisons in the germplasm evaluation program at MARC. In *Proceedings of the Beef Improvement Federation*. Asheville, NC.

Cuthbertson AZ, Deland MP, Siebert BD (1990) The production efficiency of cattle of different breed and mature live weight. *Proceedings of the Australian Society of Animal Production* **18**, 467.

Dairy Australia (2011) *Rearing Healthy Calves*. <http://www.dairyaustralia.com.au/Animals-feed-and-environment/Animal-welfare/Calf-welfare/Rearing-healthy-calves-manual.aspx>.

Davenport MD, Tiefenbacher S, Lutz CK, Novak MA, Meyer JS (2006) Analysis of endogenous cortisol concentrations in the hair of rhesus macaques. *General and Comparative Endocrinology* **147**, 255–261. doi:10.1016/j.ygcen.2006.01.005.

Davidson A, Lawson K, Kokic P, Elliston L, Nossal K, Beare S, Fisher BS (2006) Native vegetation management on broadacre farms in New South Wales: impacts on productivity and Returns. ABARE eReport 06.3. Australian Bureau of Agricultural and Resource Economics, Canberra.

DCC (2008) *National Greenhouse Gas Inventory 2006*. Emissions Analysis Team, Department of Climate Change, Canberra.

Desjardins RL, Worth DE, Vergé XPC, Maxime D, Dyer J, Cerkowniak D (2012) Carbon footprint of beef cattle. *Sustainability* **4**, 3279–3301. doi:10.3390/su4123279.

Deswysen AG, Dutilleul P, Godfrin JP, Ellis WC (1993) Nycterohemeral eating and ruminating patterns in heifers fed grass or corn silage: analysis by finite Fourier transform. *Journal of Animal Science* **71**, 2739–2747.

Dickerson GE (1970) Efficiency of animal production: molding the biological components. *Journal of Animal Science* **30**, 849–859.

Dickerson GE, Künzi N, Cundiff LV, Koch RM, Arthaud VH, Gregory KE (1974) Selection criteria for efficient beef production *Journal of Animal Science* **39**, 659–673.

Dinkel CA, Brown MA (1978) An evaluation of the ratio of calf weaning weight to cow weight as an indicator of cow efficiency. *Journal of Animal Science* **46**, 614–617.

Dixon R, Coates D (2009) Review: near infrared spectroscopy of faeces to evaluate the nutrition and physiology of herbivores. *Journal of Near Infrared Spectroscopy* **17**, 1–31. doi:10.1255/jnirs.822.

Dobos RC (2007) Quantitative analysis of behaviour of grazing dairy cows. PhD thesis. Animal Science, University of New England, Armidale, NSW.

Dobos RC, Herd R (2008) Spectral analysis of feeding patterns of steers divergent in residual feed intake. *Australian Journal of Experimental Agriculture* **48**, 843–846. doi:10.1071/EA08021.

Dove H, Axelson A (1979) Estimation of milk consumption in beef calves using a tritiated water dilution technique. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**, 666–672. doi:10.1071/EA9790666.

Dove H (2009) *Methods and Possibilities for Determining Feed Intake of Grazing Ruminants*. Livestock Breeding for GHG Outcomes Workshop. March 2009, Wellington, NZ.

DPI (2013) *BeefSpecs. A Tool to Assist in Meeting Market Specifications*. Department of Primary Industries. <http://beefspecs.agriculture.nsw.gov.au/>.

Dunn BH (2000) Characterization and analysis of the beef cow-calf enterprise of the Northern Great Plains using standardized performance analysis. PhD thesis. South Dakota State University.

Dunn BH (2002) Measuring cow-calf profitability and financial efficiency. In *Proceedings of the 34th Annual Research Symposium and Annual Meeting of the Beef Improvement Federation*. Omaha, Nebraska. <http://www.bifconference.com/bif2002/BIFsymposium_pdfs/Dunn_02BIF.pdf>.

Elwert C, Dove H (2005) Estimation of roughage intake in sheep using a known daily intake of a labelled supplement. *Animal Science* **81**, 47–56. doi:10.1079/ASC41940047.

Emmans GC, Kyriazakis I (2000) Issues arising from genetic selection for growth and body composition characteristics in poultry and pigs. In *The Challenge of Genetic Change in Animal Production*. (Eds WG Hill, SC Bishop, M McGuirk, JC McKay, G Simm and AJ Webb) pp. 39–52. Occasional Publication. British Society of Animal Science, Edinburgh.

Falconer LL, Parker JL, McGrann JM (1999) Cost of production analysis for the Texas cow-calf industry. *Texas Journal of Agriculture and Natural Resources* **12**, 7–13.

Farquharson R (1993) What is the cost of feed? *Proceedings of the National Conference of the Beef Improvement Association of Australia* **3**, 33–40. Beef Improvement Association of Australia, Ballarat.

Featherstone AM, Langemeier MR, Ismet M (1997) A nonparametric analysis of efficiency for a sample of Kansas beef cow farms. *Journal of Agricultural and Applied Economics* **29**, 175–184.

Ferrell CL, Jenkins TG (1998) Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period: I. Angus, Belgian Blue, Hereford, and Piedmontese sires. *Journal of Animal Science* **76**, 637–646.

Ferrell CL, Jenkins TG (2006) Matching genetics with production environment. In *Proceedings of the Beef Improvement Federation*. Choctaw, MS.

FFSC (2008) *Financial Guidelines for Agricultural Producers*. Farm Financial Standards Council. CD.

Field TG, Taylor RE (2003) *Beef Production and Management Decisions*. 4th edn. Prentice Hall, New Jersey.

Freer M, Dove H, Nolan JV (2007) *Nutrient Requirements of Domesticated Ruminants*. CSIRO Publishing, Melbourne.

Geay Y (1984) Energy and protein utilization in growing cattle. *Journal of Animal Science* **58**, 766–778.

Greene W (1980) Maximum likelihood estimation of econometric frontier functions. *Journal of Econometrics* **41**, 215–226.

Greenwood PL, Cafe LM, Hearnshaw H, Hennessy DW, Thompson JM, Morris SG (2006) Long-term consequences of birth weight and growth to weaning on carcass, yield and beef quality characteristics of Piedmontese- and Wagyu-sired cattle. *Australian Journal of Experimental Agriculture* **46**, 257–269.

Greiner SP (2009) *Beef Cow Size, Efficiency, and Profit*. <http://pubs.ext.vt.edu/news/livestock/old/aps-200904_Greiner.html>.

Griffith GR, Alford AR, Davies BL, Herd RM, Parnell PF, Hegarty RS (2004) An assessment of the economic, environmental and social impacts of NSW Agriculture's investment in the net feed efficiency R,D&E cluster. Economics Research Report No. 18. NSW Department of Primary Industries, Armidale, August. <http://www.dpi.nsw.gov.au/research/areas/biosecurity/economics-research/reports/err18>.

Guilbert HR, McDonald A (1934) Weight records on purebred beef cattle during growth, gestation and lactation, together with data on reproduction. *Journal of Animal Science* **1934**, 244–253.

Gunsett FC (1986) Problems associated with selection for traits defined as a ratio of two component traits. *Proceedings of the 3rd World Congress on Genetics Applied to Livestock Production* **11**, 437–442. Lincoln, Nebraska.

Hailu G, Jeffrey S, Unterschultz J (2005) Cost efficiency for Alberta and Ontario dairy farms: an interregional comparison. *Canadian Journal of Agricultural Economics* **53**, 141–160. doi:10.1111/j.1744-7976.2005.00314.x.

Hawken RJ, Zhang YD, Fortes MRS, Collis E, Barris WC, Corbett NJ, Williams PJ, Fordyce G, Holroyd RG, Walkley JRW, Barendse W, Johnston DJ, Prayaga KC, Tier B, Reverter A, Leinert SA (2012) Genome-wide association studies of female reproduction in tropically adapted beef cattle. *Journal of Animal Science* **90**, 1398–1410. doi:10.2527/jas.2011-4410.

Hayes B, Goddard M, Macleod I, Chamberlain A (2006) Selection markers for net feed intake. PCT/AU2006/001842.

Hegarty RS (2009) A genetic basis for a low methane phenotype? In *Livestock Breeding for GHG Outcomes*. MAFF, PGGRC and Learn Workshop, 3–5 March. (Ed. R Hegarty). MAFF, Wellington, NZ. <http://www.livestockemissions.net/reports,listing,16,animal-variation-workshop-nz-2009.html>.

Hegarty RS, Goopy JP, Herd RM, McCorkell B (2007) Cattle selected for lower residual feed intake have reduced daily methane production. *Journal of Animal Science* **85**, 1479–1486. doi:10.2527/jas.2006-236.

Henning JIF, Strydom DB, Willemse BJ (2011) Developing a financial ratio benchmarking system for GWK district farmers in South Africa. In *18th International Farm Management Congress*. Methven, Canterbury, NZ. <http://www.ifmaonline.org/pdf/congress/11_Henning_etal_P366-379.pdf>.

Herd RM, Arthur PF (2009) Physiological basis for residual feed intake. *Journal of Animal Science* **87**, E64–E71. doi:10.2527/jas.2008-1345.

Herd RM, Bishop SC (2000) Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. *Livestock Production Science* **63**, 111–119. doi:10.1016/S0301-6226(99)00122-0.

Herd RM, Pitchford WS (2011) Residual feed intake selection makes cattle leaner and more efficient. *Recent Advances in Animal Nutrition – Australia* **18**, 45–60.

Herd RM, Oddy VH, Richardson EC (2004) Biological basis for variation in residual feed intake in beef cattle. 1. Review of potential mechanisms. *Australian Journal of Experimental Agriculture* **44**, 423–430. doi:10.1071/EA02220.

Herd RM, Arthur PF, Archer JA (2006) Repeatability of residual feed intake and interaction with level of nutrition in Angus cows. *Proceedings of Australian Society of Animal Production*. Short Communication No. 80.

Herd RM, Arthur PF, Archer JA (2011) Associations between residual feed intake on ad libitum, pasture and restricted feeding in Angus cows. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **19**, 47–50.

Herd RM, Arthur P, Bottema C, Egarr A, Geesink G, Lines D, Piper S, Siddell J, Thompson J, Pitchford W (2013) Genetic divergence in residual feed intake affects growth, feed efficiency, carcass and meat quality characteristics of Angus steers in a large commercial feedlot. *Animal Production Science* **53**. (In press).

Hill RA (ed.) (2012) *Feed Efficiency in the Beef Industry*. Wiley and Blackwell, Oxford.

Hoag DL (2009) *Applied Risk Management in Agriculture*. 1st edn. CRC Press, Boca Raton.

Holmes P (2010) Southern beef situation analysis. MLA Report B.COM.0255. Meat and Livestock Australia, Sydney.

Howden SM, White DH, McKeon GM, Scanlan JC, Carter JO (1994) Methods for exploring management options to reduce greenhouse gas emissions from tropical grazing systems. *Climatic Change* **27**, 49–70. doi:10.1007/BF01098473.

IMF (2009) *Export and Import Price Index Manual: Theory and Practice*. International Monetary Fund, International Labour Organization, Organization for Economic Co-operation and Development, Statistical Office of the European Communities (Eurostat) and UN Economic Commission for Europe. World Bank, Washington, DC. <https://www.imf.org/external/np/sta/xipim/pdf/xipim.pdf>.

Iraizoz B, Bardaji I, Rapun M (2005) The Spanish beef sector in the 1990s: impact of the BSE crisis on efficiency and profitability. *Applied Economics* **37**, 473–484. doi:10.1080/0003684042000295359.

Jenkins TG, Ferrell CL (1994) Productivity through weaning of nine breeds of cattle under varying feed availabilities: I. initial evaluation. *Journal of Animal Science* **72**, 2787–2797.

Jenkins TG, Ferrell CL (2002) Beef cow efficiency revisited. In *Proceedings of the Beef Improvement Federation*. Omaha, New England.

Johnson DE, Johnson KA, Baldwin RL (1990) Changes in liver and gastrointestinal tract energy demands in response to physiological workload in ruminants. *Journal of Nutrition* **120**, 649–655.

Johnson JJ, Dunn BH, Radakovich JD (2010) Understanding cow size and efficiency. In *Beef Improvement Federation 42th Annual Research Symposium and Annual Meeting*. pp. 62–70. Columbia, MO.

Johnston DJ, Herd RM, Kadel MJ (2002) Evidence of IGF1 as a genetic indicator of feed efficiency traits in beef cattle. In *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production*. CD ROM Communication. No. 10–16. Institut Nacional de la Recherche Agronomique, Montpellier, France.

Johnston DJ, Barwick SA, Corbet NJ, Fordyce G, Holroyd RG, Williams PJ, Burrow HM (2009) Genetics of heifer puberty in two tropical beef genotypes in northern Australia and associations with heifer- and steer-production traits. *Animal Production Science* **49**, 399–412. doi:10.1071/EA08276.

Jones FM, Accioly JM, Copping KJ, Deland MPD, Graham JF, Hebart ML, Herd RM, Laurence M, Lee SJ, Speijers EJ, Pitchford WS (2013) Divergent genotypes for fatness or residual feed intake in Angus cattle. 1. Pregnancy rates of heifers were more affected by weight and fat than age. *Animal Production Science* **53**.

Kaliel D, Kotowich J (2002) *Economic Evaluation of Cow Wintering Systems: Provincial Swath Grazing Survey Analysis*. Alberta Production Economics Branch, Alberta Agriculture Food and Rural Development, Edmonton.

Karagiannis G, Midmore P, Tzouvelekas V (2004) Parametric decomposition of output growth using a stochastic input distance function. *American Journal of Agricultural Economics* **86**, 1044–1057. doi:10.1111/j.0002-9092.2004.00652.x.

Kelly AK, McGee M, Crews DH, Sweeney T, Boland TM, Kenny DA (2010) Repeatability of feed efficiency, carcase ultrasound, feeding behaviours, and blood metabolites in finishing heifers divergently selected for residual feed intake. *Journal of Animal Science* **88**, 3214–3225. doi:10.2527/jas.2009-2700.

Kennedy BW, van der Werf JHJ, Meuwissen THE (1993) Genetic and statistical properties of residual feed intake. *Journal of Animal Science* **71**, 3239–3250.

Khumbakar SC, Lovell CAK (2000) *Stochastic Frontier Analysis*. Cambridge University Press, Cambridge.

Kinghorn BP (1985) Modelled relationships between animal size and production efficiency. *Journal of Animal Breeding and Genetics* **102**, 241–255. doi:10.1111/j.1439-0388.1985.tb00693.x.

Kinghorn BP (2000) The genetic basis of crossbreeding. In *Animal Breeding: Use of New Technologies*. (Eds BP Kinghorn, JHJ Van der Werf and M Ryan). Post Graduate Foundation in Veterinary Science, University of Sydney.

Klasing KC, Leshchinsky TV (2000) Interactions between nutrition and immunity: lessons from animal agriculture. In *Nutrition and Immunology: Principles and Practice*. (Eds ME Gershwin, JB German and CL Keen) pp. 363–373. Elsevier, Amsterdam.

Kleiber M (1932) Body size and metabolism. *Hilgardia* **6**, 315–349.

Kleiber M (1961) *The Fire of Life*. John Wiley and Sons, New York.

Koch RM, Swiger LA, Chambers D, Gregory KE (1963) Efficiency of feed use in beef cattle. *Journal of Animal Science* **22**, 486–494.

Kolath WH, Kerley MS, Golden JW, Keisler DH (2006a) The relationship between mitochondrial function and residual feed intake in Angus steers. *Journal of Animal Science* **84**, 861–865.

Kolath WH, Kerley MS, Golden JW, Shahid SA, Johnson GS (2006b) The relationships among mitochondrial uncoupling protein 2 and 3 expression, mitochondrial deoxyribonucleic acid single nucleotide polymorphisms, and residual feed intake in Angus steers. *Journal of Animal Science* **84**, 1761–1766. doi:10.2527/jas.2005-519.

Koopmans TC (1951) Analysis of production as an efficient combination of activities. In *Activity Analysis of Production and Allocation: Cowles Commission for Research in Economics Monograph 13*. (Ed. TC Koopmans) pp. 33–97. John Wiley and Sons, New York.

Koots KR, Gibson JP, Wilton JW (1994) Analyses of published genetic parameter estimates for beef production traits. 2. Phenotypic and genetic correlations. *Animal Breeding Abstracts* **62**, 825–853.

Lanna DP (2009) Evaluation of net feed intake, biological efficiency, profit and GHG emissions in the Brazilian beef cattle industry. In *Livestock Breeding for GHG Outcomes*. MAFF, PGGRC and Learn Workshop, 3–5 March. (Ed. R Hegarty). MAFF, Wellington, NZ. <http://www.livestockemissions.net/reports,listing,16,animal-variation-workshop-nz-2009.html>.

Laurence M, Accioly JM, Copping KJ, Deland MPB, Graham JF, Hebart ML, Herd RM, Jones FM, Lee SJ, Speijers EJ, Pitchford WS (2013) Divergent genotypes for fatness or residual feed intake in Angus cattle. 2. Body composition but not reproduction was affected in first-parity cows on both low and high levels of nutrition. *Animal Production Science* **53**.

Lee GJ (2000) Sources of variation in pasture intake of sheep and its relationship with productivity. PhD thesis. University of New England, Armidale.

Long CR, Cartwright TC, Fitzhugh HA (1975) Systems analysis of sources of genetic and environmental variation in efficiency of beef production: cow size and herd management. *Journal of Animal Science* **40**, 409–420.

Loy D, Tait JR (2011) *National Program for Genetic Improvement of Feed Efficiency in Beef Cattle.* <http://www.nbcec.org/FeedEfficiencyBeefCattleISU.pdf>.

Luiting P, Urff EM (1991) Residual feed consumption in laying hens. 1. Quantification of phenotypic variation and repeatabilities. *Poultry Science* **70**, 1663–1672. doi:10.3382/ps.0701663.

Ma H, Raeb AN, Huang J, Rozel S (2007) Enhancing productivity on suburban dairy farms in China. *Agricultural Economics* **37**, 29–42. doi:10.1111/j.1574-0862.2007.00220.x.

MacNeil MD (2005) Genetic evaluation of the ratio of calf weaning weight to cow weight. *Journal of Animal Science* **83**, 794–802.

Mathis CP, Sawyer JE (2000) *Beef Cow Efficiency in the Southwest.* College of Agriculture and Home Economics, New Mexico State University. <http://www.spiritviewranch.com/pdfstatic/BeefCowEfficiency.pdf>.

Mbaga MD, Romain R, Larue B, Lebel L (2003) Assessing technical efficiency of Quebec dairy farms. *Canadian Journal of Agricultural Economics* **51**, 121–137. doi:10.1111/j.1744-7976.2003.tb00169.x.

McCosker TH (2011) *Grazing for Profit: School Course Notes.* Resource Consulting Services. <www.rcs.au.com>.

McCosker T, McLean D, Holmes P (2010) Northern beef situation analysis 2009. Final MLA report. Project B.NBP.0518. Meat and Livestock Australia, Sydney.

Melton BE (1995) Profiting from change in the U.S. beef industry: genetic balance for economic gains. Technical Report of the National Cattlemen's Association. Englewood, CO.

Miller AJ, Faulkner DB, Knipe RK, Strohbehn DR, Parrett DF, Berger L (2001) Critical control points for profitability in the cow-calf enterprise. *Professional Animal Scientist* **17**, 295–302.

MLA (2004) *The Producers's Manual*. Meat and Livestock Australia, Sydney.

MLA (2012a) *Feed Demand Calculator.* Meat and Livestock Australia, Sydney. <http://www.mla.com.au/publications-tools-and-events/tools-and-calculators/feed-demand-calculator>.

MLA (2012b) *More Beef from Pastures. Module 6: Weaner Throughput.* Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Research-and-development/Extension-and-training/More-Beef-from-Pastures>.

Mlote SN, Mdoe NSY, Isinika AC, Mtenga LA (2013) Estimating technical efficiency of small scale beef cattle fattening in the lake zone in Tanzania. *Journal of Development and Agricultural Economics* **5**, 197–207.

Montanholi YR (2007) Genetic improvement in beef cattle for feed efficiency: increasing our understanding of the biological basis. *Beef Improvement Federation Annual Research Symposium* **39**, 110–125.

Montanholi YR, Swanson KC, Palme R, Schenkel FS, McBride BW, Lu D, Miller SP (2010) Assessing feed efficiency in beef steers through feeding behaviour, infrared thermography and glucocorticoids. *Animal* **4**, 692–701. doi:10.1017/S1751731109991522.

Montaño-Bermudez M, Nielsen MK, Deutscher GH (1990) Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. *Journal of Animal Science* **68**, 2279–2288.

Moore SS, Crews DH, Nkrumah D (2006) Multiple and candidate gene approaches to genetic evaluation of feed efficiency in beef cattle. In *8th World Congress on Genetics Applied to Livestock Production,* 13–18 August, Belo Horizonte, Brazil.

Moore SS, Sherman EL, Nkrumah JD (2008) Associations of single nucleotide polymorphisms and haplotypes with feed intake and feed efficiency in beef cattle. PCT/IB2008/000558.

Murillo-Zamorano RL (2004) Economic efficiency and frontier techniques. *Journal of Economic Surveys* **18**, 33–77. doi:10.1111/j.1467-6419.2004.00215.x.

Nicol AM, Brookes IM (2007) The metabolisable energy requirements of grazing livestock. In *Pasture and Supplements for Grazing Animals*. (Eds PV Rattray, IM Brookes and AM Nicol) pp. 10 151–10 172. Occasional Publication No. 14. New Zealand Society of Animal Production.

Nkrumah JD, Li C, Yu J, Hansen C, Keisler DH, Moore SS (2005) Polymorphisms in the bovine leptin promoter associated with serum leptin concentration, growth, feed intake, feeding behaviour, and measures of carcass merit. *Journal of Animal Science* **83**, 20–28.

Nkrumah JD, Okine EK, Mathison GW, Schmid K, Li C, Basarab JA, Price MA, Wang Z, Moore SS (2006) Relationships of feedlot feed efficiency, performance and feeding behaviour with metabolic rate, methane production and energy partitioning in beef cattle. *Journal of Animal Science* **84**, 145–153.

Nkrumah JD, Basarab JA, Wang Z, Li C, Price MA, Okine EK, Crews DH, Moore SS (2007a) Genetic and phenotypic relationships of feed intake and different measures of feed efficiency with growth and carcass merit of beef cattle. *Journal of Animal Science* **85**, 2711–2720. doi:10.2527/jas.2006-767.

Nkrumah JD, Sherman EL, Li C, Marques E, Crews DHJrBartusiak R, Murdoch B, Wang Z, Basarab JA, Moore SS (2007b) Primary genome scan to identify putative QTL for feedlot growth rate, feed intake and feed efficiency of beef cattle. *Journal of Animal Science* **85**, 3170–3181. doi:10.2527/jas.2007-0234.

Nossal K, Sheng Y, Zhao S (2008) Productivity in the beef cattle and slaughter lamb industries. Research Report 08.13. Australian Bureau of Agricultural and Resource Economics, Canberra.

Notter DR (2002) Defining biological efficiency of beef production. In *Proceedings of the Beef Improvement Federation.* Omaha, NE.

NRC (1996) *Nutrient Requirements of Beef Cattle*. 7th rev. edn. National Research Council. National Academy Press, Washington, DC.

O'Hara P, Freney J, Ulyatt M (2003) *Abatement of Agricultural Non-carbon Dioxide Greenhouse Gas Emissions. A Study of Research Requirements*. Ministry of Agriculture and Forestry, Wellington, NZ.

Ostergaard V, Korver S, Solbu H, Andersen BB, Oldham J, Wiktorsson H (1990) Main report: EAAP working group on efficiency in the dairy cow. *Livestock Production Science* **24**, 287–304. doi:10.1016/0301-6226(90)90008-T.

Palme R, Rettenbacher S, Touma C, El-Bahr SM, Möstl E (2005) Stress hormones in mammals and birds: comparative aspects regarding metabolism, excretion, and noninvasive measurement in fecal samples. *Annals of the New York Academy of Sciences, Trends in Comparative Endocrinology and Neurobiology* **104**, 162–171.

Pitchford WS (2004) Genetic improvement of feed efficiency of beef cattle: what lessons can be learnt from other species?

Australian Journal of Experimental Agriculture **44**, 371–382. doi:10.1071/EA02111.

Pitchford WS, Barlow R, Hearnshaw H (1993) Growth and calving performance of cows from crosses between the Brahman and Hereford. *Livestock Production Science* **33**, 141–150. doi:10.1016/0301-6226(93)90245-D.

Pitchford W, Bottema C, Naik M (2006) Quantitative trait loci for bovine net feed intake. PCT/AU2006/001970.

Pullar JD, Webster AJF (1977) The energy cost of protein and fat deposition in the rat. *British Journal of Nutrition* **37**, 355–361. doi:10.1079/BJN19770039.

PWC (2011) *The Australian Beef Industry: The Basics.* Price, Waterhouse and Coopers. <http://www.pwc.com.au/industry/agribusiness/assets/Australian-Beef-Industry-Nov11.pdf>.

Ramsey R, Doye DG, Ward CE, McGrann JM, Falconer L, Land Bevers SJ (2005) Factors affecting beef cow-herd costs, production, and profits. *Journal of Agricultural and Applied Economics* **37**, 91–99.

Rattray PV, Brookes IM, Nicol AM (2007) *Pasture and Supplements for Grazing Animals*. Occasional Publication No. 14. New Zealand Society of Animal Production.

Rauw WN, Kanis E, Noordhuizen EN, Groomers FJ (1998) Undesirable side effects of selection for high production efficiency in farm animals: a review. *Livestock Production Science* **56**, 15–33. doi:10.1016/S0301-6226(98)00147-X.

RCS (2013) *ProfitProbe: The RCS Business Analysis and Benchmarking Tool*. Resource Consulting Services. <http://www.rcs.au.com/consultingservices/category_7/index.htm>.

Reynolds WL, DeRouen TM, Moin S, Koonce KL (1980) Factors influencing gestation length, birth weight and calf survival of Angus, Zebu and Zebu cross beef cattle. *Journal of Animal Science* **51**, 860–867.

Richards TJ, Jeffrey SR (2000) Efficiency and economic performance: an application of the MMIC model. *Journal of Agricultural and Resource Economics* **25**, 232–251.

Richardson EC, Herd RM (2004) Biological basis for variation in residual feed intake in beef cattle. 2. Synthesis of results following divergent selection. *Australian Journal of Experimental Agriculture* **44**, 431–440. doi:10.1071/EA02221.

Richardson EC, Herd RM, Archer JA, Woodgate RT, Arthur PF (1998) Steers bred for improved net feed efficiency eat less for the same feedlot performance. *Animal Production in Australia* **22**, 213–216.

Richardson EC, Herd RM, Archer JA, Arthur PF (2004) Metabolic differences in Angus steers divergently selected for residual feed intake. *Animal Production Science* **44**, 441–452. doi:10.1071/EA02219.

Ritchie HD (1995) The optimum cow: what criteria must she meet? In *Proceedings of the 27th Beef Improvement Federation*. Sheridan, Wyoming. <http://www.spiritviewranch.com/pdfstatic/TheOptimumCow.pdf>.

Robinson DL (1996) Estimation and interpretation of direct and maternal genetic parameters for weights of Australian Angus cattle. *Livestock Production Science* **45**, 1–11.

Robinson DL, Oddy VH (2004) Genetic parameters for feed efficiency, fatness, muscle area and feeding behaviour of feedlot finished beef cattle. *Livestock Production Science* **90**, 255–270. doi:10.1016/j.livprodsci.2004.06.011.

Rolfe DF, Newman JM, Buckingham JA, Clarke MG, Brand MD (1999) Contribution of mitochondrial proton leak to respiration rate in working skeletal muscle and liver and to SMR. *American Journal of Physiology* **276**, C692–C699.

Sackett D, McEachern S (2003) *AgInsights 2003*. Holmes Sackett and Assoc., Wagga Wagga, NSW.

Samarajeewa S, Hailu G, Jeffrey SR, Bredahl M (2012) Analysis of production efficiency of beef cow/calf farms in Alberta. *Applied Economics* **44**, 313–322. doi:10.1080/00036846.2010.507173.

Samuelson PA, Nordhaus WD (2004) The production-possibility frontier. In *Economics.* 18th edn. (Eds PA Samuelson and WD Nordhaus) pp. 9–15. McGraw-Hill/Irwin, New York.

Sawyer GJ, Speijers EJ, Morris RJ, Coupar FJ (1994) Characterising lactation curves in heifers of different breeds 1st calved in moderate or low condition. *Proceedings of the Australian Society of Animal Production* **20**, 128–131.

Scholtz MM, Roux CZ (1984) Correlated response to selection for growth, size and efficiency. In *Proceedings of the 2nd World Congress on Sheep and Beef Cattle Breeding* (Eds JH Hofmeyr and EHH Meyer) pp. 433–443. Pretoria, South Africa.

Schroeder TC, Mintert J, Barzle F, Gruenwald O (1988) Factors affecting feeder cattle price differentials. *Western Journal of Agricultural Economics* **13**, 71–81.

Seman DH, Stuedemann JA, Anderson JE (1997) Spectral analysis of bovine grazing behaviour on *Neotyphodium coenophialum* infested tall fescue. *Applied Animal Behaviour Science* **54**, 73–87. doi:10.1016/S0168-1591(97)00082-8.

Seman DH, Stuedemann JA, Hill NS (1999) Behaviour of steers grazing monocultures and binary mixtures of alfalfa and tall fescue. *Journal of Animal Science* **77**, 1402–1411.

Sheng Y, Zhao S, Nossal K (2011) Productivity and farm size in Australian agriculture: reinvestigating the returns to scale. In *Proceedings of the Australian Agricultural and Resource Economics Society,* 9–11 February, Melbourne.

Sherman EL, Nkrumah JD, Murdoch BM, Moore SS (2008) Identification of polymorphisms influencing feed intake and efficiency in beef cattle. *Animal Genetics* **39**, 225–231. doi:10.1111/j.1365-2052.2008.01704.x.

Sherman EL, Nkrumah JD, Li C, Bartusiak R, Murdoch B, Moore SS (2009) Fine mapping quantitative trait loci for feed intake and feed efficiency in beef cattle. *Journal of Animal Science* **87**, 37–45. doi:10.2527/jas.2008-0876.

Sherman EL, Nkrumah JD, Moore SS (2010) Whole genome single nucleotide polymorphism associations with feed intake and feed efficiency in beef cattle. *Journal of Animal Science* **88**, 16–22. doi:10.2527/jas.2008-1759.

Standish B (2000) *Economics: Principles and Practice*. Pearson Education, South Africa.

Stroup WW, Nielsen MK, Gosey JA (1987) Cyclic variation in cattle feed intake data: characterization and implications for experimental design. *Journal of Animal Science* **64**, 1638–1647.

Taylor RE, Field TG (1999) *Beef Production and Management Decisions*. 3rd edn. Prentice Hall, New Jersey.

Taylor JF, McKay SD, Rolf MM, Ramey HR, Decker JE, Schnabel RD (2012) Genomic selection in beef cattle. In *Bovine Genomics*. (Ed. JE Womack) pp. 211–233. John Wiley and Sons, Oxford.

Taylor St CS (1987) An evaluation of genetic size-scaling in breed and sex comparisons of growth, food efficiency and body composition. *Proceedings of the Australian Association of Animal Breeding and Genetics* **6**, 1–12.

Thompson JM, Barlow R (1986) The relationship between feeding and growth parameters and biological efficiency in cattle and sheep. *Proceedings of the 3rd World Congress on Genetics Applied to Livestock Production* **11**, 271–282. Lincoln, Nebraska.

Thonney ML, Touchberry IRW, Goodrich RD, Meiske JC (1976) Intraspecies relationship between fasting heat production and bodyweight: a reevaluation of $W^{0.75}$. *Journal of Animal Science* **43**, 692–704.

Trestini S (2006) Technical efficiency of Italian beef cattle production under a heteroscedastic non-neutral production frontier approach. In *Proceedings of the 10th Joint Conference on Food, Agriculture and the Environment*, 26–30 August. Centre for International Food and Agricultural Policy, Duluth, Minnesota.

USDA (1992) *Guidelines for Production and Financial Performance Analysis for the Cow-Calf Producers: Cow-Calf SPA*. Extension Service, US Department of Agriculture, Washington, DC.

USDA (2012) *National Program for Genetic Improvement of Feed Efficiency in Beef Cattle.* US Department of Agriculture, Washington, DC. <http://www.beefefficiency.org/info/USDAFeedEfficiencyinBeefCattleGeneral.pdf>.

Vargas CA, Olson TA, Chase CC Jr, Hammond AC, Elzo MA (1999) Influence of frame size and body condition score on performance of Brahman cattle. *Journal of Animal Science* **77**, 314–319.

Veerkamp RF, Emmans GC, Crombi AR, Simm G (1995) Variance components for residual feed intake in dairy cows. *Livestock Production Science* **41**, 111–120. doi:10.1016/0301-6226(94)00056-D.

Villano R, Fleming E, Rodgers H (2009) Productivity and returns to resources in the beef enterprises on Victorian farms in the South-West Farm Monitor Project. *Australian Farm Business Management Journal* **6**, 83–88.

Walker RH, Fell LR, Reddacliff LA, Kilgour RJ, House JR, Wilson SC, Nicholls PJ (2007) Effects of yard weaning and training on the behavioural adaptation of cattle to a feedlot. *Livestock Science* **106**, 210–217. doi:10.1016/j.livsci.2006.08.004.

Walmsley BJ, Oddy VH, McPhee MJ, Mayer DG, McKiernan WA (2010) BeefSpecs a tool for the future: on-farm drafting and optimising feedlot profitability. *Australian Farm Business Management Journal* **7**, 29–36.

Wiedemann S (2012) Allocation between high value co-products. From Livestock: A Case Study from Australian Sheep Production. In *Proceedings of the 8th International Conference on LCA in the Agri-Food Sector*. 2–4 October, pp. 682–685. Rennes, France.

Williams Y, Wright A (2005) Variation in methane output between sheep. In *Abstracts Greenhouse 2005: Action on Climate Change*. 13–17 November. CSIRO Publishing, Melbourne.

Wilson RH, Charry AA, Kemp DR (2004) Whole farm financial performance indicators and benchmarks in Australian agriculture: a review. AFBM Network Discussion Paper 05. <http://louisewww.mit.csu.edu.au/faculty/science/saws/afbmnetwork/papers/Benchmarking220604(WilsonCharryKemp).pdf>.

Wilson S, Dobos RC, Fell LR (2005) Spectral analysis of feeding and lying behaviour of cattle kept under different feedlot conditions. *Journal of Applied Animal Welfare Science* **8**, 13–24. doi:10.1207/s15327604jaws0801_2.

Wolcott ML, Graser H-U, Johnston DJ (2010) Effects of early weaning on growth, feed efficiency and carcass traits in Shorthorn cattle. *Animal Production Science* **50**, 315–321. doi:10.1071/AN09153.

Wood BJ, Archer JA, van der Werf JHF (2004) Response to selection in beef cattle using IGF-1 as a selection criterion for residual feed intake under different Australian breeding objectives. *Livestock Production Science* **91**, 69–81. doi:10.1016/j.livprodsci.2004.06.009.

Zimmerman PR (2012) *Method and System for Monitoring and Reducing Ruminant Methane Production*. <http://patentscope.wipo.int/search/en/detail.jsf?docId=WO2009151927&recNum=287&docAn=US2009044990&queryString=ALL:(grainstoragebin)&maxRec=1301>.

19 Environmental management

N. Reid, D.A. Norton and M. Stafford Smith

INTRODUCTION

It is ironic that in these environmentally aware times, when the extent of the interconnections between the biogeochemical, ecological and social systems operating across the planet has now been deduced, and when world leaders have repeatedly affirmed their commitment to sustainable development, that the gulf between humanity's aspirational goal of planetary environmental stewardship and its achievement has never been so large. Progress being made globally to achieve the millennium development goals and alleviate human suffering and poverty (UN 2012) has often come at the expense of many of the world's natural ecosystems, with the concomitant loss of ecosystem goods and services. Accordingly, the net gains of development are often less than thought (MEA 2005a). For example, 'Expansion of livestock production around the world has often led to overgrazing and dryland degradation, rangeland fragmentation, loss of wildlife habitat, dust formation, bush encroachment, deforestation, nutrient overload through disposal of manure, and greenhouse gas emissions' (MEA 2005a).

It is not only meat and livestock production that has brought the world to this point (MEA 2005b). The environmental challenge facing humanity is manifold and growing. Climate change due to greenhouse gas (GHG) emissions, the increasing human population, the massive increase in the size of the world's middle class projected by 2030 (UNDP 2013) and the concomitant increase in meat consumption and luxury goods derived from animal products (e.g. leather and wool), all have major implications for meat and livestock production globally. The likely expansion in extent and intensification of beef production will put more pressure on marginal lands (MEA 2005b) as well as increase the risk of degradation of productive lands and waters. Sound environmental management of the meat and livestock industries has never been more important for human well-being, the maintenance of global life-support systems and the survival of planetary biodiversity (the diversity of life on Earth).

This chapter addresses these challenges by considering several themes.

1. The global environmental challenge is briefly reviewed in order to understand the need and drivers for best-practice environmental management in the beef industry. All elements of the meat and livestock industry, from the farm level to the global industry as a whole, are examples of complex adaptive systems. This conceptual framework helps to understand and anticipate a range of otherwise seemingly incomprehensible and complex system behaviours and 'wicked problems' (i.e. diabolical public policy issues resistant to solution; APSC 2007).
2. The newly emerging paradigm of resilience-based ecosystem stewardship in natural resource management is outlined. This framework provides new goals for planetary stewardship and novel insights into the way in which meat and livestock production systems might be better managed and administered in future.
3. From this emerges the range of sustainability targets that beef producers must aspire to in the environmental, social, economic and managerial dimensions. The

environmental and social characteristics of different beef production systems are examined, and ecological and socio-economic indicators that producers can use to monitor the performance of their environmental management are outlined.

4. Three case studies are profiled to illustrate environmental issues that individual managers deal with routinely, with examples of the on-farm solutions that have been developed in response.
5. Finally, the management and policy implications of important cross-scale and cross-level issues are highlighted, particularly the wicked problems associated with meat production and consumption that will challenge humanity and the integrity of the biosphere in coming decades.

THE GLOBAL ENVIRONMENTAL CHALLENGE IN THE 21ST CENTURY

For most of human evolution, people interacted with the environment at a local scale, and human impacts on the environment were minor in comparison with the forces of nature. The megafaunal extinctions consequent upon the arrival of modern people in previously unpopulated continents and islands (e.g. in northern Eurasia, the Americas and Australasia) over the past 50 000 years are a notable exception. The retreat of the northern ice sheets at the end of the Pleistocene, 12 000 years ago, and the rise of agriculture and civilisation saw the beginning of a fundamental change in the scale and intensity of the interactions between people and their environment. Human transformation of the biosphere continued to accelerate as a result of the industrial revolution from ~1800 as new technologies were harnessed. Then, from ~1950, numerous indicators of human impact on the biosphere increased exponentially, in an event that has been termed the 'great acceleration' (Steffen *et al*. 2004; Syvitski 2012).

The extraordinary changes to the biosphere over the past two centuries have led to calls to recognise the recent human history of massive global change as a new geological epoch, the Anthropocene (Syvitski 2012). The change from one geological epoch to another is recorded as a stratigraphic event in the history of the world's rocks, such as a change in climate or mass extinction event, sea-level rise or rapid changes in the deposition of different types of sedimentary rocks. The Anthropocene is associated with unprecedented human impacts on global biogeochemical processes since 1950 in more ways than just climate change, as a result of dramatic increases in human population, economic activity, transport, communications, urbanisation, agricultural intensification, damming of the world's rivers, and resource consumption (Steffen *et al*. 2007; Syvitski 2012). Atmospheric carbon dioxide and other greenhouse gases, global surface temperature and human-induced nitrogen fluxes in the coastal zone have all increased. Land use and land cover have changed dramatically, with deforestation for agriculture and urbanisation outstripping reforestation. Intensification of land and water use for food and fibre production and to support urbanisation has seen low-input primary production systems transformed to high-input farming and grazing systems and irrigated agriculture and aquaculture. Almost half of the global land surface is now domesticated for human use, resulting in land and water degradation due to unsustainable practices and accelerating rates of species extinctions (MEA 2005a,b; Fig. 19.1). In combination with water, gas and oil extraction, river regulation and impoundments have led to reductions in sediment delivery to estuaries, causing large deltas to sink at a rate four times that of sea-level rise (Syvitski and Kettner 2011). Resources are being extracted and consumed at increasing rates, and most of the world's fisheries are fully or over-exploited. These changes are unidirectional and accelerating in the early 21st century, and some of them will be clearly evident in the future geological record.

In recognition of the pervasive and escalating impacts of development on the global environment, and the desirability of sustaining the life-support systems and ecosystem services of our current world for future generations,

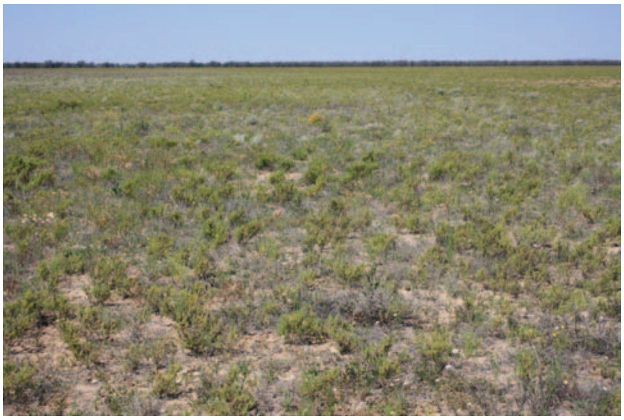


Figure 19.1: Overgrazing of perennial grassland on the Darling River floodplain, NSW, has changed it to a degraded ephemeral herbland with a loss of grassland species, grazing production and seasonal and inter-annual system stability. Source: N. Reid.

the World Commission on Environment and Development (WCED 1987) proposed the goal of sustainable development as 'the use of the environment and resources to meet the needs of the present without compromising the ability of future generations to meet their own needs'. Recognising that since then we have failed to pay attention to the extent to which we may be damaging our life-support system, Griggs *et al.* (2013) proposed to amend the definition to 'Development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends'. In either case, the concept of sustainability (= production + conservation) focuses on the concept of human well-being. This means access to the material needs for a good life, personal security, freedom and choice, and the support and comfort of a caring community (Dasgupta 2001; Chapin *et al.* 2009). Sustainability and well-being are value-based concepts, so sustainability assessment is as much a political as a scientific process. However, maintenance and improvement of planetary life-support capacity and the continued ability for people to enjoy the multiple benefits of the ecological functioning of the biosphere (i.e. ecosystem services; Costanza *et al.* 1997) are fundamental to the notion of sustainability (Chapin *et al.* 2009).

In order to understand the impact of global change on human well-being, the UN's Millennium Ecosystem Assessment (MEA 2005a,b) assessed the continued ability of the world's ecosystems and ecosystem services to support humanity. The MEA confirmed that humans have changed ecosystems more rapidly and extensively over the past 50 years than at any other time in human history, to meet the rapidly growing demands for food, fresh water, timber, fibre and fuel. The changes to ecosystems have contributed to substantial net gains to economic development and most people's quality of life. However, the material improvements have come at the cost of the substantial and largely irreversible loss of biodiversity and degradation of more than 50% of the ecosystem services upon which humanity depends, albeit indirectly, for survival and well-being. The MEA (2005a,b) also found increased risk of ecosystem collapse (i.e. abrupt changes in ecosystem structure and function) and worsening poverty for some people, despite a reduction in the proportion of people in extreme poverty (UN 2012). These adverse changes in the condition and trend of the biosphere could grow significantly worse during the first half of this century, and could undermine the achievements of the UN's Millennium Development Goals (UN 2012). Significant changes in policies, institutions and practices are required globally to reverse the degradation of ecosystems while meeting increasing demands for ecosystem services (MEA 2005b).

Where does this leave beef producers and the meat and livestock industries? What should the environmental management objectives be for the beef industry, agricultural corporations, family farms, feedlots and for processors and distribution networks further down the value chain? These questions, which are the focus of the later parts of this chapter, are especially relevant in a country such as Australia where the extent of native vegetation used for grazing spans 46.3% of the continent (Lesslie and Mewett 2013) and sown and irrigated pastures a further 9.5% of land area. The most recent State of the Environment report in Australia (State of the Environment 2011) identified:

> Invasive species … and grazing [as] having a significant impact on much of our land environment. Grazing is Australia's most widespread land use and its environmental impact appears to be mixed, with impacts diminished in some regions but increased in others since widespread monitoring began in 1992 ... Land clearing [mainly for agriculture] is slowing, but still averaged around 1 million hectares per year during 2000–10. The legacy impacts of land clearing are substantial, with loss and fragmentation of native vegetation … there have been major declines in many components of biodiversity since European settlement, and data on pressures suggest that many species continue to decline.

The response of Australian governments to deteriorating land condition was initially weak. Some early soil conservation legislation left it to landholders to decide whether action to curb soil loss was required (Bradsen 1988). This approach was superseded in time by an over-reliance on 'command-and-control' laws prohibiting certain forms of environmental destruction (IC 1998). Much of the considerable regulation of this nature is *ad hoc*, poorly drafted, often the only policy response, developed without input from affected landowners, prescriptive rather than outcomes-focused (and therefore inefficient and often ineffective), and unenforced. More recently, policy approaches to curbing land degradation and restoring landscapes affected by agriculture have aimed to build social and individual capacity in rural communities. They include Landcare, property planning and catchment management as well as holistic and similar management philosophies that have arisen from within the grazing industry (Fig. 19.2; Gardiner and Reid 2010).

Figure 19.2: Cattle grazing one paddock ahead of a sheep flock as part of the leader–follower variant of high-intensity, short-duration, long-rest ('planned') grazing at Lana, a 3350 ha beef cattle and fine wool property on the New England tablelands, northern NSW. This form of grazing management (Butterfield *et al.* 2006) and its observance of the six key paddock indicators (see text) has allowed stocking rate to increase over time (although it remains conservative by district standards) and native birds, microbats, platypus, koala, grazing-sensitive herbs and other environmental values (e.g. clean water in streams, native tree regeneration) to prosper (Wright *et al.* 2004; Reid and Zirkler 2006). Source: D. Norton.

Incentives-based instruments that encourage landholders to manage the environment sustainably in their own interest have yet to dominate the policy environment, despite repeated calls over the past two decades (IC 1998; ANRA 2009).

MEAT AND LIVESTOCK ENTERPRISES AS SOCIAL–ECOLOGICAL SYSTEMS

In recent decades, the science of natural resource management has changed rapidly as the simplistic assumptions and underlying conceptual models of successive natural resource management frameworks have been found wanting. Up to the 1970s, natural resource management was generally spread across multiple silos in both government and academic institutions, for example in separate departments of range, forestry, wildlife, fisheries, soil conservation, water resources, park management, agriculture and so on. Management tended to focus on single issues (e.g. livestock, timber, game, soil erosion, water supply, wildland recreation, nature conservation, crop production, etc.) within a command-and-control framework of top-down management designed to maximise yields of the desired resource (e.g. forage), suppress disturbances that affect productivity (e.g. fire) and compensate for natural climatic fluctuations (e.g. drought: Holling and Meffe 1996; Hilderbrand *et al.* 2005). The purpose was to turn an unpredictable and inefficient natural system into one that produced the desired resource in a predictable and economically efficient way by suppressing variability and preventing system change. By reducing the system's range of natural variation and adaptive capacity to respond to disturbance, however, the frequent result was loss of system resilience (Gunderson 2000). As resilience decreases, the likelihood of disturbance shifting a system into an undesired or degraded state increases, resulting in management surprises and socio-economic crises, such as woody encroachment or desertification of rangelands, wildfires and debilitating pest outbreaks in production forests, long-term vegetation change, biodiversity loss and fishery collapses (Holling 1973).

Given global change and the loss of resilience and productivity of ecosystems under siloed, command-and-control management at multiple scales, it is folly to manage ecosystems with a single objective and in a single state based on past reference points, which has traditionally been the goal of resource and conservation managers alike (Chapin *et al.* 2009). Rather, management needs to be flexible and aimed at sustaining the functional properties and resilience of productive systems in the face of continuing change. Management that responds to and attempts to influence change in beneficial ways for both the environment and society is called 'resilience-based ecosystem stewardship'. This newly emerging paradigm of natural resource management focuses on resilience, a concept that acknowledges change as an inherent part of social–ecological systems and aims to sustain and promote the fundamental functions, structures, identity and feedbacks crucial to life on Earth. It reframes management units such as farms as ecosystems that provide a suite of ecosystem services, not just a single resource like beef or wool. The concept of stewardship invokes 1) the integral role of people in managing the production of a wide range of ecosystem services, goods and 'bads', 2) humanity's responsibility for sustaining the Earth system and avoiding the loss of future options, and 3) recognition that the capacity of social–ecological systems to provide services is constrained by the life-support system of the planet (Fig. 19.3). But herein lies a wicked problem. Most management of the biosphere and production of goods and services is driven primarily by self-interest and market forces or the pressures of subsistence, whether it be the management of a farmer, family, tribe, people, country or continent vis à vis rivals at the same level with

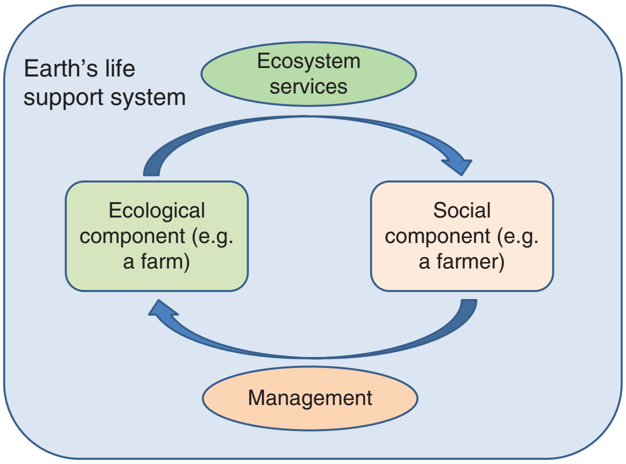


Figure 19.3: Social–ecological systems reflect the interactions between ecological and social components of ecosystems at a range of scales from the paddock or farm to the planet. Source: Adapted from Chapin *et al.* (2009).

competing interests. Collective action at the highest level, however, is required to protect the global life-support system. This is exceedingly difficult to orchestrate as it means putting aside individual, corporate and sectarian interests for the sake of the common good.

Physical, ecological, social and cultural changes in the Earth system are all highly interconnected so a broad transdisciplinary framework encompassing ecology, sociology, economics, political science and the law is required to monitor, interpret and influence change in coupled social–ecological systems. The processes that link the social and ecological subsystems structure the dynamics of such systems: floods, droughts and food and water quality affect the human subsystem. Cultural norms, peer pressure, the social, regulatory and policy environment and world markets affect the on- and off-farm environment and farm productivity through their influence on farm management. Sustainable management and policies must be simultaneously ecologically, economically and culturally viable to succeed. A systems perspective is required to understand the dynamics of integrated social–ecological systems (Chapin *et al.* 2009). Such systems can be defined in terms of various scales (e.g. spatial, temporal, jurisdictional, management and policy; Cash *et al.* 2006) and at many levels (e.g. from a paddock to the entire planet in terms of spatial scale). The size, shape and boundaries of social–ecological systems depend on the scale and level of the management problem and the objectives being addressed.

Social–ecological processes connect the components of the system and can be primarily ecological (e.g. pasture production), socio-economic (e.g. tenure systems) or a mix of both (e.g. stocking rate decisions driven by cost of inputs). Amplifying and stabilising feedbacks are especially important interactions between components because they have predictable outcomes in terms of internal system dynamics (Chapin *et al.* 2009). Amplifying (or positive) feedbacks cause two interacting components to change in the same direction, increasing process rates and destabilising the system. For example, increasing stocking rate may reduce a farmer's debt in the short term but lead to overgrazing and eventual ecosystem collapse in the medium term (Fernández *et al.* 2002). Amplifying feedbacks often underlie management trade-offs, where the livestock producer is forced to forgo short-term profit for persistence of the resource base and a sustained income over the longer term. By way of example, fencing livestock from riparian zones is costly but can lead to on- and off-farm improvements in water quality, with potential production benefits associated with clean drinking water for livestock as well as significant downstream economic and environmental benefits for other catchment users and biodiversity benefits (Fig. 19.4; Chichilnisky and Heal 1998; Lardner *et al.* 2005).

In contrast to amplifying feedbacks, stabilising (or negative) feedbacks cause two interacting components to change in opposite directions. Grazing by cattle causes forage biomass to decline whereas rest from grazing allows forage biomass to increase, allowing sustainable grazing at intermediate levels of livestock and forage

Figure 19.4: A thickly vegetated riparian zone along a backwater near Moree, north-western NSW. Well-managed riparian zones offer a diversity of ecosystem services including reduced erosion, clean water both on-farm and downstream, and enhanced biodiversity. Source: N. Reid.

biomass ('safe' utilisation rates; Hunt 2008). Stabilising feedbacks often underpin management synergies. For instance, investing in better livestock genetics can translate into fewer animals needed to achieve a given level of meat production, but with lower variable costs and therefore more profit (Kemp and Michalk 2011).

Social–ecological systems are complex adaptive systems because the interactions between components cause them to adjust to changes in conditions. Livestock productivity responds positively to fertiliser and clover amendment of native pastures over time on the northern tablelands of NSW, with the increase in soil nutrients and grazing pressure leading to a shift in pasture composition towards more productive, nutrient-responsive, grazing-tolerant, native grasses (Lodge and Whalley 1989). In other words, the balance between the various components in the system adapts to the alteration in soil fertility and grazing pressure. Social–ecological systems also exhibit strong path dependence or legacy effects of the past on current system behaviour. A fire in native grassland on a property might cause a stand of wattle (*Acacia* sp.) to spontaneously regenerate in a paddock that was cleared of native timber 30 years ago but not in the adjacent field that was cleared more than 100 years ago. The disparate effects of fire in the two otherwise identical pastures is due to the disparate history of the two areas and the hard seed of legumes, which remain viable for ~50 years in the soil until a fire breaks dormancy and permits their germination (Noble and Slatyer 1980).

If conditions change enough to alter the interactions between components, complex adaptive systems are prone to more fundamental change. Pushed beyond a certain threshold, social–ecological systems can transition to an alternative stable state defined by a new balance of system components with differing responses to disturbance. Open grassy poplar box woodland and shrub-invaded dense shrub woodland are alternative stable states of the dominant range type on the Cobar pediplain in western NSW (Fig. 19.5; Harrington *et al*. 1984). Periodic wildfire maintains the grassy woodland in an open state, killing any newly established shrub seedlings, but it has little impact on mature shrubs other than defoliation, so that burnt shrub-invaded woodland remains in a closed state regardless (Westoby *et al*. 1989). Reversing such state transitions can be difficult; it requires substantial management inputs and an accurate understanding of the changes that have occurred (CWWCMA 2010).

Changes in the state of social–ecological systems depend on critical slow variables that change slowly through time (relative to human timeframes) but have a major influence on system components and their interactions (Chapin *et al*. 2009). Soil properties, hydrological response, the presence of certain functional types of plants, disturbance regimes, the regulatory environment and culture are all examples of slow variables (Fig. 19.6). The removal of deep-rooted woody native vegetation and its conversion to crops and pastures reduces evapotranspiration, increases the flux of rainwater past the root zone and can cause water tables to rise. Over the 20th century, the inexorable rise of saline water tables affected an estimated 2.5 million ha of land in agricultural districts across southern Australia (PMSEIC

Figure 19.5: Two different ecosystem states in grassy poplar box woodland on the Cobar pediplain near Coolibah, western NSW. Left: relatively unmodified woodland that is managed with fire and is uninvaded by woody regrowth. Right: woodland invaded by unpalatable shrubs and regenerating cypress pine, largely lacking a herbaceous ground flora, with little value for grazing and with different native biodiversity values. Source: N. Reid.

1999), rendering 0.8 million ha useless for agricultural production (ABS 2002) and placing 5.7 million ha at risk of dryland salinity in southern and eastern Australia. Because of the gradual nature of aquifer rise and the depth of the water table in many districts, by the time that farmers and scientists realised the scale of the potential damage, it was too late. The amount of land at risk of salinity could triple to 17 million ha by 2050 (NLWRA 2001). Salinisation has been a frequent cause of desertification of irrigation zones throughout history (Dregne 1983) but its potential impact on dryland farming is only now evident.

Slow variables (e.g. soil nutrient status) in social–ecological systems influence or interact with fast variables that fluctuate much more rapidly on a daily, seasonal or interannual basis (Chapin *et al.* 2009). Examples of fast variables in meat and livestock production systems include volatility in prices received (interacting with slower variables of animal productivity to determine total product sales), daily and seasonal rainfall (or lack thereof, interacting with slowly changing soil characteristics to determine pasture production), and individual extreme climatic events and natural disasters such as fire and floods (interacting with the slowly changing adaptive capacity of an enterprise to determine whether it survives a given event). The impact of fast variables is highly visible and attracts most management and public attention, but slow variables and persistent unidirectional change are, in fact, more critical to long-term sustainability (Fig. 19.6). Similarly important is the role of disturbance to the long-term stability of social–ecological systems and the ability to understand the role of different kinds of disturbance in avoiding undesirable system change and hastening desirable transitions (Westoby *et al.* 1989).

Figure 19.6: Nutrient inputs through pasture improvement with fertiliser, sown grasses and legumes have resulted in elevated soil phosphorus and nitrogen levels which, coupled with timber clearance and loss of natural control agents dependent on the original native understorey, has resulted in sustained outbreaks of herbivorous insects such as Christmas beetles and widespread defoliation and mortality of remaining trees (dieback) on the New England tablelands in northern NSW (Reid 2000; Reid and Landsberg 2000). Source: D. Norton.

All systems experience disturbances such as droughts, pest outbreaks, global economic shocks, sudden loss of markets or abattoir closures, leading to disruption, reorganisation and renewal of the social–ecological system. In recent years, the Australian meat and livestock industries have endured the global financial crisis, some of the worst natural disasters (fire, floods, droughts) in history and the temporary closure of the live export trade to Indonesia (Chapter 12). Over a slightly longer timeframe, the abolition of the wool floor price scheme in 1991 (Massy 2012) and changes in the market competitiveness of natural and synthetic fibres precipitated restructuring in the Australian wool industry, not all of it positive (Vanclay 2003). More often than not, the system adapts and recovers, but not without pain for some participants and benefit to others. Occasionally, the shock is of sufficient magnitude to drive wholesale transformation, pushing the social–ecological system into a completely new state. The invasion of Australia by the English in 1788 led to the overthrow of the hunter–gatherer subsistence life-styles of the indigenous inhabitants by an export-market-oriented, capitalist system of livestock production across almost the entire continent in little more than a century.

The concept of 'adaptive cycles' of system disruption, renewal and reorganisation (Holling 1973; Chapin *et al.* 2009) provides a framework to interpret the response of social–ecological systems to shocks of various kinds. An adaptive cycle is initiated by a disturbance that causes rapid change in most properties of the system, called the 'release' phase. This is followed by a 'renewal' phase as the system regenerates to a similar state, or in the case of regime shift, to some new state. The relatively brief renewal phase provides a narrow window for change, allowing the pre-existing social and ecological components to re-establish or allowing an opportunity for new actors and structures to emerge from the remains of the previous state.

The development of irrigation districts in the Murray–Darling Basin from the 1880s led to a series of 'release and renewal' phenomena, giving rise to promising new intensive farming communities from the holdings of former extensive pastoral properties in various parts of the basin. After renewal comes 'growth', as the biological entities in social–ecological systems mature (e.g. irrigation zones are developed, and orchards and vineyards are established), the physical properties of the system are gradually modified (e.g. windbreaks mature and extensive irrigation and water storages change the local and regional microclimate) and socio-economic structures and management are regularised (e.g. water sharing and trading rules and conditions are developed).

In the absence of further disturbance, the system moves into the 'conservation' phase, characterised by complex social and ecological interconnections and specialised actors. Established irrigation zones such as the Murrumbidgee Irrigation Area fall into this category. Social–ecological systems typically spend most of their time in this steady-state phase, during which they become increasingly vulnerable to disturbance because of the complex web of feedbacks that develop to maintain the system in its mature state. Changes in any of the myriad social and ecological conditions within the system or external shocks can trigger new release. Droughts in the 1980s, 1990s and 2000s triggered a basin-wide water reform process that threatens the viability of businesses and irrigation communities unable or unwilling to adapt to changing circumstance. Sometimes the simple fact of ageing of established social–ecological systems and structures is sufficient to precipitate decay, release and renewal as the external environment overtakes a farming district and consigns its run-down farms, yesterday's business models and ageing communities to rural backwaters until a new generation of farmers, technologies and business structures move in to trigger release and renewal.

Social–ecological systems pertinent to the meat and livestock industries occur across a wide variety of levels and scales, from smallholder subsistence livelihoods, hobby farms, commercial properties, family businesses and agricultural companies, to vertically integrated corporations operating globally, as well as encompassing major regions of the world and various ethnic groups dedicated primarily to livestock production. The challenge of resilience-based ecosystem stewardship is to identify and understand the properties and mechanisms that underpin the cyclical patterns of change in ostensibly different social–ecological systems. This enables those involved in the livestock production sector to anticipate and influence opportunities for renewal of existing successful systems, or to effect beneficial change and regime shift where necessary, while minimising the negative impacts of disruption during episodes of release.

Given the transdisciplinary nature of meat and livestock production, it is clear that sustainable environmental management must be integrative and avoid the risk of becoming yet another silo. Livestock managers must weigh up a wide range of evidence from different sources in developing sustainable environmental management solutions, always mindful of the next shock likely to affect their operation. Trade-offs and synergies between different components (Chapter 20) are an inevitable consequence of the behaviour of complex adaptive systems. The art of being a successful livestock producer involves the ability to integrate all these considerations with a flexible and sustainable system perspective, and to anticipate and be ready to adapt management in response to new information and circumstance.

SUSTAINABLE MANAGEMENT OF BEEF PRODUCTION SYSTEMS

A spectrum of beef production systems

Livestock production is the most extensive land use at the global level as it is in Australia, where it occupies 55.7% of the continent (Lesslie and Mewett 2013). Accordingly, beef production is undertaken in a wide range of environments across Australia. For convenience we refer to three environmental zones defined by ABARES (2013): the high-rainfall zone (>500 mm mean annual rainfall in the Mediterranean zone and >800 mm in eastern Australia), the wheat–sheep zone (300–500 mm in the Mediterranean zone and 400–800 mm in eastern Australia), and the arid and semi-arid pastoral zone (northern Australia and inland southern Australia). Given this wide range of biophysical environments, beef enterprises vary considerably in scale and intensity of production. Sustainability issues in social–ecological systems vary greatly with scale and level (Cash *et al.* 2006), so for simplicity, we recognise three points on a continuum of beef production scale and intensity: feedlots, sown-pasture-based beef production systems, and extensive rangeland pastoralism.

1. Feedlots are at the most intense extreme on the spectrum, with stock densities of 5000–6000 DSE/ha within a feedlot. However, feedlots occupy a tiny area, both in terms of the average area per feedlot (1–15 ha) and in absolute terms: the 450 or so accredited feedlot sites in Australia sum to only 1000–2000 ha in total across the country (Chapter 11). While the ecological footprint of individual feedlots is much larger, Australian feedlots only account for ~2% of the Australian herd at any one time.

2. Sown and amended pasture-based systems of beef production, often dominated by exotic pasture species, in the medium- to high-rainfall zones are characterised by intermediate intensities of production (1–20 DSE/ha) and occupy intermediate areas of land both in terms of area per farm business (700–1800 ha) and in absolute terms – 9.4% of Australia is devoted to the grazing of modified pastures (Lesslie and Mewett 2013; Chapters 10, 15). In June 2012, 58% of the Australian herd occurred on farms in ABARES' high-rainfall and wheat–sheep zones, with 34% across southern Australia and 25% in the medium- to high-rainfall zones in Queensland.
3. Rangeland pastoral systems occur mainly in the arid and semi-arid zone and are primarily based on grazing native vegetation. Rangeland properties (stations) are characterised by little human modification of the vegetation composition (though possibly considerable impact on its condition), large size (averaging 115 000 ha in the northern pastoral zone and 225 000 ha in the south; ANRA 2009), low rates of primary production (stocking rates of <1 DSE/ha) and together occupy the largest area of Australia of any land use (46.3%: Lesslie and Mewett 2013; Chapter 9). At June 2012, 42% of the Australian herd was located in ABARES' pastoral zone, most (38% of the national herd) being located across northern Australia (Kimberley, Northern Territory and pastoral Queensland).

There are, of course, all manner of intermediate situations. Feedlots are often part of grazing properties in the high-rainfall, wheat–sheep or pastoral zones. Some farms in the medium- to high-rainfall zone have a production base of low-input native pastures, and a third of the area of beef enterprises in the northern Australian pastoral zone consists of sown pastures of introduced species, such as buffel grass (ANRA 2009), as well as varying degrees of native vegetation modification, including woody vegetation clearance and native pasture amendment with phosphorus-based fertilisers and tropical legumes.

Only ~65% of Australia's beef production comes from specialist beef producers (ABARES 2013), as many farm businesses operate additional enterprises. Fine wool and prime lamb production is frequently combined with beef cattle in the high-rainfall and pastoral zones, and dryland and irrigated cropping enterprises are frequently combined with mixed livestock enterprises in the wheat–sheep zone. Additional specialised beef production systems occur; these include finishing cattle on 1.2 million ha of irrigated pastures (0.2% of the area of Australia) and intensive grazing of plantations of tree legumes such as leucaena in tropical Australia.

Sustainability issues and scale

Livestock production systems influence their social, economic and biophysical environment across a range of spatial scales. Sustainable farms minimise negative impacts and maximise positive impacts across all dimensions (social, economic, biophysical) and spatial scales through striving to achieve a wide range of sustainability objectives. The sustainable management of livestock enterprises must encompass not only biophysical resource and environmental considerations but a range of social and economic management issues, including the impact of farm management on the well-being of families living on the farm, employees, neighbours and the local community residing nearby; consumers, businesses and markets purchasing the farm's products, sometimes on the other side of the world; and the health of the farm business. These considerations range in spatial scale from on-farm (e.g. the profitability and financial prognosis of the farm business, and the health and well-being of the farm manager, employees and their families), to district-wide (e.g. the health and well-being of neighbours and employees who reside elsewhere in the district) and global considerations (e.g. overseas markets and consumers; Table 19.1; Chapters 1, 12).

In a similar manner, the environmental impact of farm management includes on- and off-farm considerations. Within the farm boundaries, biophysical considerations include the welfare of the livestock and working animals, the condition and trend in water, soil and pasture resources and biodiversity assets, and air quality. Off-farm environmental impacts include downstream and off-site pollution (e.g. excess runoff and groundwater accessions, sediment, nutrients, pesticides and dust) and noise, as well as the impacts of on-farm management as a source of introduced pests and weeds and on district- and regional-scale habitat connectivity for native biodiversity. Global impacts include the farm's contribution to GHG emissions. The fundamental motivations for wanting to achieve various sustainable management objectives include (IC 1998):

1. private interest, such as maintaining the short- and long-term productivity and profitability of the enterprise and wanting what's best for one's family;
2. wanting to avoid socio-economic and ecological externalities in the pursuit of profitable production, such as ensuring that the water quality of rivers and streams

Table 19.1: Relevance of social, economic, environmental and management considerations in sustainable farm management at various spatial scales

Dimension	On-farm	Off-farm		
Consideration		**Adjacent to farm and district scale**	**Catchment and regional scale**	**National and global scale**
Social				
Farm workers	✓	–	–	–
Families living on-farm	✓	–	–	–
Families of farm workers living off-farm	–	✓	–	–
Neighbours	–	✓	–	–
Suppliers and contractors	✓	✓	✓	–
Local community	–	✓	✓	
Consumers		✓	✓	✓
Businesses along supply and value-adding chain and final markets	✓	✓	✓	✓
Philanthropy	–	✓	✓	✓
Economic				
Business plan	✓	✓	✓	✓
Farm financial ratios	✓	–	–	–
Farm financial projections	✓	–	–	–
Sustainability trend analysis	✓	✓	✓	✓
Environmental				
Atmosphere	✓	✓	✓	✓
Soil	✓	✓	–	–
Surface waters (farm dams, rivers and streams, natural wetlands)	✓	✓	✓	–
Groundwater	✓	✓	✓	–
Pastures	✓	–	–	–
Weeds	✓	✓	–	–
Vertebrate pests	✓	✓	–	–
Remnant woody vegetation	✓	–	–	–
Native biodiversity	✓	–	–	–
Habitat connectivity	✓	✓	✓	–
Livestock and farm animal welfare	✓	–	–	–
Grazing management	✓	–	–	–
Management				
Environmental planning	✓	✓	✓	✓
Environmental management	✓	–	–	–
Environmental monitoring	✓	–	–	–

leaving a property is at least as good as when it entered the property;

3. public good, where the altruistic notions of environmental stewardship dominate decision-making, with no expectation of a reciprocal private-good return on one's investment.

In a capitalist economy like Australia, private interest is transacted in the marketplace and consumers and producers negotiate over price. Since there are tens of thousands of beef producers producing much the same product, beef prices leave producers with little margin for altruistic or public-good demonstrations of environmental stewardship or duty of care unless there are additional advantages to the producer, such as by way of advertising.

Objectives of sustainable livestock management

The key sustainability objectives for livestock production systems are outlined in this section, with the relevant spatial scales of each indicated in Table 19.1. The sustainability objectives are grouped in terms of the different dimensions of sustainability and the key considerations relevant to each. These sustainability objectives have been pooled from various sources including Mason *et al.* (2003), Reid (2006), Pannell *et al.* (2006), Malcolm *et al.* (2009), Gardiner and Reid (2010), MLA (2012b) and Norton and Reid (2013). Integration of management objectives across the various dimensions of sustainability is essential if livestock production systems are to be managed as sustainable social–ecological systems.

Social issues and management objectives

The social objectives that a meat and livestock producer considers in managing a sustainable farm and beef operation are likely to include (in no particular order):

- health, well-being, happiness and adequate education of themselves and their family;
- a robust family succession plan;
- provision of a healthy living environment for all the families living on the farm and positive tenancy arrangements;
- health, well-being and adequate induction of farm workers and contractors working on the farm and provision of a safe, on-farm, working environment and adequate facilities;
- provision of positive conditions of employment including appropriate remuneration and training for farm workers;
- any other issues on the farm's social responsibility agenda;
- avoidance of health risks for families living off-farm due to contact with farm workers;
- positive neighbour relations, and negligible pollutants (e.g. dust, odours, sediment, nutrients, pesticides), pests, disease, weeds, weed seeds or noise leaving the farm or affecting adjacent properties;
- conduct of an ethical business and adoption of best business practices in relation to suppliers, contractors and any businesses along the supply and value-adding chain, including final markets;
- support of local businesses, services and community events and organisations;
- sale of healthy, ethical, sustainably produced meat and other livestock products to buyers and consumers, and provision of consumer information about the farm's products, environment and business philosophy;
- philanthropic and personal support of appropriate charities, not-for-profit organisations and local community institutions and volunteer services, in keeping with the farm's business philosophy and vision.

Economic management objectives

Economic management objectives for sustainable beef management are likely to include:

- development, frequent use of and regular review of the farm business plan and key performance indicators, embodying social and environmental responsibility and continuous improvement principles, to guide management and the decision-making priorities and policies of key staff;
- monitoring of farm financial indices and ratios (e.g. total assets, debts and equity at the start and end of each year, and annual cash flow and profit), which indicate growth in wealth over time, so that farm solvency, liquidity, profitability and return on total capital are in the 'good' or better range (Chapter 20);
- farm financial projections and farm financial modelling undertaken regularly with the most likely projections being positive, but also used to test other possible scenarios;
- trends in the ratio of total costs to total income are declining year on year (assuming the business structure is not changing through time), implying increasing business efficiency, and assuming (ii) the change in real total costs from year to year is monitored to know whether the business is increasing or decreasing production in moving towards maximum profitability;
- generating a decent income to meet short and longer term family goals of financial independence and security.

Biophysical issues and management objectives

Sixteen goals have been suggested for the sustainable management of agro-ecosystems for sustainable livestock production (Gardiner and Reid 2010; Table 19.2). These arise from wider considerations of the characteristics of sustainable biophysical systems that broadly relate to the cycling of matter, maximising plant productivity, the way

Table 19.2: Characteristics of sustainable livestock production systems

Farming system
1. Use land within its capability
2. Enhance on-farm natural resources
3. Generate positive off-farm environmental externalities
4. Optimise the net social benefit of agriculture
5. Develop stable, resilient and flexible farming systems to manage climate and market risks

Livestock
6. Set stocking rates to achieve high animal production per head and less than maximum production per hectare

Atmosphere
7. Offset greenhouse gas emissions and manage a carbon-neutral or positive farm business

Energy efficiency
8. Increase the energy efficiency of agricultural production

Soil
9. Increase the quantity, quality and health of soil over time
10. Maximise nutrient cycling and the activity of the soil decomposer chain

Groundcover
11. Achieve high (>80%) if not maximum groundcover in the form of ground-layer vegetation and litter to prevent erosion and evaporation of soil moisture

Rainfall and irrigation water
12. Maximise infiltration of rainfall and irrigation water in soil and its use by agricultural plants by minimising evaporation, surface runoff and deep drainage

Pasture composition
13. Maintain pasture composition in terms of palatable persistent perennial grasses, responsive legumes and palatable 'gap fillers'

Livestock drinking water
14. Maintain clean drinking water for livestock

Vertebrate pests
15. Maintain vertebrate pest numbers at economically non-damaging levels

Remnant vegetation, waterways, wildlife and biodiversity
16. Retain, restore and revegetate natural areas for biodiversity conservation

Source: Gardiner and Reid (2010).

the system responds to shocks, and the role of diversity. These targets provide a context within which to consider sustainability objectives for livestock production systems from an environmental perspective.

The biophysical issues and management objectives for sustainable beef production in the medium- to high-rainfall zones are likely to include the following.

Atmosphere

- Adoption of a GHG neutrality strategy for the farm business through on-farm energy conservation and renewable energy initiatives, green-power and off-farm investments, and on-farm carbon-sequestration and conservation initiatives. However, with present technology, regulations and price settings, it is uncertain how many Australian livestock producers in the medium- and high-rainfall zones can afford to be carbon-neutral, so this objective will remain aspirational for many.
- Avoidance of offensive odours and dust leaving the farm and affecting neighbours.

Soil

- Improvement in soil quality (e.g. fertility, soil organic carbon) and quantity (i.e. forming rather than losing soil).
- Avoidance of erosion and soil degradation (i.e. soil salinisation, structural decline and acidification) in on-farm production zones and correction of soil limitations through appropriate soil amendments as necessary (e.g. lime, gypsum, potash, dolomite).

Surface waters

- Exclusion of livestock from surface waters (i.e. farm dams, rivers and streams, natural wetlands) and seeps and waterlogged areas prone to pugging (MLA 2012b).
- Reticulation of clean drinking water for livestock.

- Development of filter strips of thick grass and deep-rooted woody vegetation bordering waterways and natural wetlands to filter runoff and nutrients from overland and subsurface flow.
- Maintenance of dense grass in floodways.

Groundwater

- A target of 30% of the farm landscape under deep-rooted woody vegetation to minimise deep drainage, intercept subsurface flow and reduce risk of dryland salinity (McIntyre *et al*. 2004; Gardiner and Reid 2010; MLA 2012b).
- Targeting known recharge zones and surface seeps in production zones with deep-rooted perennial pastures and woody vegetation.

Pastures

- Meeting most or all pasture forage needs with diverse, deep-rooted perennial pastures where rainfall seasonality permits (MLA 2012b).
- Restricting annual crops and pastures to special management purposes.

Weeds and vertebrate pests

- Adoption of a preventative approach to managing weeds by managing for maximum groundcover (MLA 2007), maintaining minimum (high) levels of litter and pasture biomass (MLA 2007), quarantining newly purchased livestock in designated holding areas, and using wash-down facilities for plant and vehicles.
- Coordination with neighbours to manage district-wide weed and animal pest problems (MLA 2012b).
- Maintenance of low, subeconomic, vertebrate-pest densities through continuous suppression (MLA 2012b).

Remnant vegetation, wildlife habitat and biodiversity conservation

- Management of remnant woody vegetation for biodiversity conservation in heavily cleared and modified regions (MLA 2012b).
- Management of high-conservation-value remnants as protection zones on farms with large areas of remnant woody vegetation (MLA 2012b).
- Commissioning flora and fauna surveys of on-farm flora and fauna (MLA 2012b).
- Protection and enhancement of populations of rare and endangered species, ecologically endangered communities and vegetation with high habitat values (old-growth trees, hollows, logs, wildlife food trees etc.) in on-farm conservation zones fenced from livestock (MLA 2012b).
- Return of tall native vegetation (if formerly present) to natural waterways to improve in-stream habitat.
- Provision of habitat connectivity for wildlife across farm and district with neighbours in heavily cleared and modified regions, building on and restoring natural corridors (e.g. creeks and rivers as well as roadsides), and linking remnants and on-farm plantings (MLA 2012b).
- Development of partnerships with conservation organisations, Landcare or local naturalists to periodically monitor and report on-farm populations of endangered species, condition of endangered communities and habitat restoration activities (MLA 2012b).

Animal welfare

- Strict observation of industry codes of ethical best practice in managing the welfare of livestock and working animals.

Most of the above objectives are also relevant in arid rangelands and across northern Australia, though often expressed in different ways. However, the large size of pastoral zone properties raises additional issues. Stafford Smith and McAllister (2008) categorised nine ecological strategies exhibited by arid zone biota, which give rise to nine weak points that range managers must be aware of. They reviewed a variety of regional best-practice manuals, which cover many of the above objectives, but added some specific to rangelands.

- Deliberate retention of water-remote areas coupled with the evening of grazing pressure in areas used for production. Because rangelands are semi-natural landscapes grazed on a large scale out from water points, there is a need to locate water in ways that evens up grazing to avoid localised damage (McIvor *et al.* 2010). The number of head per water point should be limited, there should be two or three waters per paddock, and the size of paddocks should not be so large that cattle are unable to reach most areas or result in large concentrations in preferred areas. However, this management trend should be tempered with preservation of some water-remote areas to support biodiversity that is otherwise lost under grazing (James *et al.* 2000).
- Use of fire to manage vegetation balance. Whereas closely settled farms mostly regard fire as a nuisance

or threat, in broad swathes of rangeland and across northern Australia where mechanical intervention is economically unviable, fire is an essential management tool, for example helping to maintain the balance between shrubs and grasses (Fig. 19.5; Purvis 1986; Landsberg *et al*. 1998; McIvor *et al*. 2010; O'Reagain and Bushell 2011).

- Proactive management of stocking numbers to account for drought risk (where various alternative strategies are viable and sustainable but others are not). The choice of stocking rate is the single major management option in rangelands and northern Australia (McIvor *et al*. 2010) where it assumes even greater significance than in other systems; a variety of strategies from low, relatively constant stocking to higher but rapidly traded numbers can be run viably with different attitudes to risk, but proactive decision-making about these is a common necessity (Foran and Stafford Smith 1991; Stafford Smith and Foran 1992; O'Reagain and Bushell 2011; O'Reagain *et al*. 2011). In their review of technical guidelines for sustainable beef production in northern Australia, McIvor *et al*. (2010) concluded that the best compromise between seasonal fluctuations in forage availability and the potential for overgrazing to reduce land condition and future productivity is to stock at around the long-term carrying capacity. Stock reductions in very dry years to avoid overgrazing and increased stock numbers in wetter years to increase income may be entertained, but carry increased ecological and economic risk compared with constant light stocking (O'Reagain *et al*. 2011).
- McIvor *et al*. (2010) also concluded that periodic pasture spelling, particularly during the first half of the growing season, was important to maintain northern Australian pastures in good condition or to restore them from poor condition and improve productivity.

Farm management issues and objectives

The objectives for farm management that a beef producer should consider in managing a sustainable farm and beef enterprise are listed here.

- Development, frequent use and periodic review of an environmental management plan based on best-practice and continuous improvement principles, such as:
- fencing land to capability (Mason *et al*. 2003);
- addressing land and water degradation issues;
- improving management efficiency and efficacy (e.g. by managing for the six paddock indicators of sustainable primary production [see below] and considering a laneway system to move livestock around the farm);
- integrating tall woody vegetation (preferably native, either planted or regrowth) in pasture in various configurations (e.g. windbreaks, blocks, alleyways, open grids) for multiple shade, shelter, wildlife and carbon sequestration benefits (MLA 2012b);
- zoning the farm into production and conservation zones (MLA 2012b);
- addressing environmental stewardship concerns in conservation zones (Morton *et al*. 1995; MLA 2012b);
- seeking management synergies where possible;
- undertaking occasional audits of the farm environmental plan and operations to ensure farm environmental management adheres to industry standards and best practice.
- Management of farms in the medium- and high-rainfall zones according to the six key paddock indicators of sustainable primary production (Gardiner and Reid 2010):
  1. maximise groundcover (80–100%; MLA 2006a,b);
  2. maintain litter at 2.0 t/ha or more, where possible;
  3. maintain 1.5–3.0 t/ha of green dry matter in pastures (MLA 2006a,b);
  4. maintain a diverse palatable pasture sward to maximise year-round production;
  5. maintain 30% of landscape under tall woody vegetation for shade, shelter and hydrological function (MLA 2012b);
  6. maintain optimal soil health.
- Regular monitoring of the six key paddock indicators for sustainable primary production.

Profit and productivity maximisation occurs when rainfall-use efficiency is maximised; this occurs on broadacre farms in the medium- to high-rainfall zones when the six paddock indicators of sustainable primary production are observed (Gardiner and Reid 2010). Under these conditions, free natural inputs are maximised, requiring a minimum of purchased inputs (Chapter 15).

The six paddock indicators do not apply to arid and semi-arid rangeland systems where 1) unpalatable woody species dominate the vegetation, 2) low rainfall and internal redistribution processes mean that the optimal ratio of sink (vegetated) and source (bare) areas corresponds to less than maximum plant cover because herbaceous production in vegetated patches is driven by runoff from inter-patches (Ludwig and Tongway 1995), or where 3) low and erratic productivity means that it is impossible to maintain residual litter and pasture biomass levels and uneconomic to correct soil nutrient deficiencies and toxicities. In these environments, useful indicators tend to be vegetation-type specific. They include maintaining a significant cover of palatable perennials (either grasses or low shrubs such as saltbush, depending on the system), not allowing the cover of unpalatable shrubs and trees ('woody weeds') to become dominant, and maintaining landscape function indicators that measure resource flows using landscape function analysis (Tongway and Hindley 2004).

MOTIVATIONS AND PRESSURES ON BEEF PRODUCERS IN RELATION TO ENVIRONMENTAL MANAGEMENT

Beef producers are subject to a wide variety of motivations and pressures to manage their farms and enterprises responsibly, and to simultaneously prioritise multiple objectives, interests and concerns. Not surprisingly, environmental management priorities often rank well behind more pressing business and personal issues, particularly the dominant signal of price received and personal, family and peer pressure. This section reports recent data about the motivations of Australian farmers to adopt sustainable land management practices, and describes the direct and indirect biophysical and socio-economic drivers of producer behaviour (Fig. 19.7) that can lead to unsustainable management and a decline in grazing land condition. The economic and policy decision-making environments are examples of indirect (or ultimate) causes of the ecological condition and health of beef properties. Price volatility in international and domestic markets has had a major impact on the structure of the Australian beef industry in recent decades (ABS 2005). However, slow variables such as primary producers' terms of trade (the 'cost–price squeeze') have been equally important, if less obvious, and contentious new regulations to price carbon and curb GHG emissions could cause major changes in the industry in the medium term (Garnaut 2008).

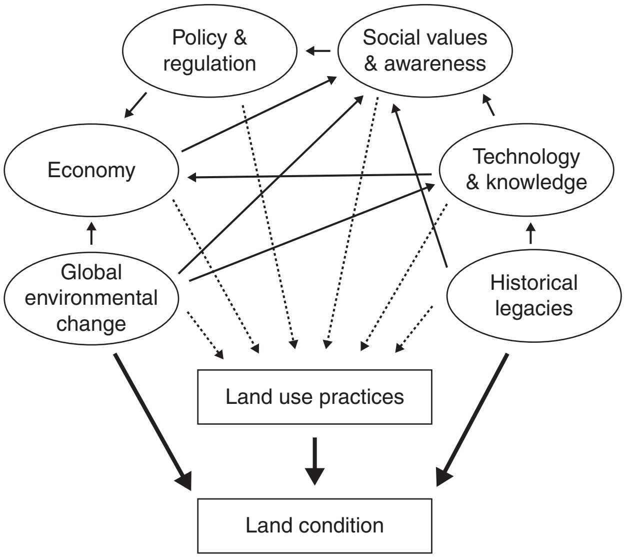


Figure 19.7: Relationships between the ultimate drivers of land condition. While all drivers directly affect land condition through their effect on land-use practices (thin solid lines), global environmental change and historical legacies also affect land condition directly (thick solid lines). Interactions (dashed lines) occur among the different drivers. Source: Modified from Norton and Reid (2013).

Motivations for environmental management

A recent survey of adoption of sustainable land management practices by Australian broadacre farmers (including specialist livestock producers and croppers as well as mixed farmers) found that between a third and half had implemented various sustainable practices relating to grazing, pasture, weed and native vegetation management (Ecker *et al.* 2013). For instance, 38–49% of broadacre farmers were managing weeds of national significance on their properties, managing for deep-rooted perennial pastures, setting minimum groundcover targets, had adopted cell grazing or strip rotational grazing, fenced native vegetation to control stock access, and planted native vegetation or encouraged native regrowth on their farms.

Financial, environmental and personal motivations were the main reasons for implementing these practices (Ecker *et al.* 2013). Financial considerations motivated 88–90% of broadacre farmers to adopt sustainable grazing and weed management practices. Improved feed availability and increased returns were the main financial reasons for 77–82% of farmers to adopt sustainable grazing practices, with increased land value being a lesser motivation (18%). Increased returns (75%) and the cost of not acting (64%) were the principal financial motivations for managing weeds, with increased land value (33%) and reduced livestock costs (18%) motivating fewer farmers. Two-thirds of farmers were also motivated by environmental factors to adopt sustainable grazing and weed management practices. The principal environmental reasons for adopting sustainable grazing practices were improved soil quality (66%), reduced runoff (47%), reduced soil loss (46%) and producers' environmental goals and beliefs (36%). The main environmental reasons for managing weeds of national significance were producers' environmental goals and beliefs (77%) and a sense of corporate social and environmental responsibility (39%). About half of broadacre farmers were motivated by personal reasons to adopt sustainable grazing (43%) and weed management practices (57%). Desire to protect the natural resource base was the most important personal motivation across all land management practices investigated.

In the case of adoption of sustainable native vegetation management practices, broadacre farmers were motivated more by environmental (79% of managers) than financial (72%) or personal (51%) considerations (Ecker *et al.* 2013). The main environmental reasons for adopting sustainable vegetation management practices were to improve soil quality (43%), be true to one's goals and beliefs (41%), provide habitat for native fauna (37%), and reduce erosion (34%), runoff (32%) and salinity and waterlogging (15%). The chief financial motivations for adopting sustainable vegetation management practices were to provide shelter for livestock and crops (68%), increase land value (33%) and income (27%), and the potential for biodiversity credits (16%).

The availability of funding support and extension advice was far less important in influencing adoption of sustainable land management practices than were farmers' financial, environmental and personal motivations (Ecker *et al.* 2013). This was likely due to the fact that farmers are more persuaded by their own research and analysis of innovations than by others' messages about novel practices, which they may already have decided are inappropriate (Pannell *et al.* 2011). Where support did influence farmers' decisions to adopt sustainable land management practices, Landcare and production groups, private consultants and regional natural resource management facilitators were important sources of support for grazing management innovation. The latter and government support were also important for encouraging adoption of native vegetation management practices. Lack of funds, lack of time and workload were the main factors preventing farmers from undertaking the environmental management they would like. The message for advisory services is that to increase awareness and adoption of sustainable farm management practices, the design of natural resource management programs for the meat and livestock industries should combine financial and environmental information with messages to conserve the farm resource base in extension and communication activities.

Pressures leading to environmental degradation

Degradation of grazing lands and associated wetlands and waterways is widely seen as one of the main consequences of the expansion in the extent and intensification of agricultural production systems at all scales, from local to global (MEA 2005a). Addressing land degradation while maintaining production is a key challenge in managing sustainable beef production systems. Understanding the pressures or drivers that lead to environmental degradation may be useful in meeting this challenge (Mattison and Norris 2005). Indeed, it is not possible to restore degraded systems without understanding these drivers and addressing them (Hobbs and Norton 1996).

Drivers of ecosystem degradation are a complex mix of proximate (direct) and ultimate (indirect) factors (Norton and Reid 2013). The proximate causes of land degradation are generally obvious; they include factors such as vegetation clearance, cultivation, overgrazing by domestic or pest animals, and woody weed invasion. The ultimate causes of land degradation, the factors that influence a farmer's day-to-day decision-making (e.g. the decision to overgraze) are often less easy to identify. However, identifying these is critical, especially at a policy level, as it is often impossible to address the proximate causes of land degradation without first addressing the underlying causes (Young 1984; Young *et al.* 1984). The ultimate drivers of land degradation can be broadly grouped into six categories: 1) historical legacies, 2) global environmental change, 3) technology and knowledge, 4) economy, 5) social values and awareness, and 6) policy and regulation (Norton and Reid 2013). The first two focus on the physical and biological environment, while the latter four are concerned with the socio-economic environment. While global environmental change and historical legacies directly affect ecosystem condition, all six indirectly affect ecosystems by influencing land managers' decisions about the way they use their land and water resources. The outcome of those decisions leads to the proximate causes of land degradation (Fig. 19.7) as a result of the cross-level and cross-scale interactions typical of complex social–ecological systems.

The following grazing example illustrates these complex interactions and how they can affect ecosystem condition. Both global environmental change and the national and international economy can place substantial pressure on the profitability of a farm business, especially where financial commitments such as mortgage payments are an issue (Chapter 20). In the case of global environmental change, this can be through changes in the frequency and intensity of extreme events such as droughts, floods, wind storms or frosts that are significant for farm production (Sillmann and Roeckner 2008; Smith 2011). In the case of the economy, factors such as increasing costs of external inputs (e.g. fuel and fertiliser) coupled with fluctuating returns for farm products are critical. One response to these types of pressure is to intensify farm management practices in order to buffer the farm business against the vagaries of unpredictable weather or markets. Intensification can involve one or more management actions (proximate causes) including increasing the carrying capacity of existing pastures (e.g. through cultivation or topdressing with seed and fertiliser), bringing new land into production through vegetation clearance, or by overgrazing the existing forage base (as a short-term strategy). All of these can result in land degradation.

Simply putting in place regulations that limit carrying capacity or vegetation clearance does not address the underlying (ultimate) reasons for these management responses. In fact, poorly thought-through regulations can result in unintended or perverse outcomes (e.g. vegetation clearance rules resulting in a flurry of land clearance before regulations are enacted). Therefore, other approaches are required (e.g. paying farmers to retain native vegetation and provide ecosystem services such as clean water and carbon sequestration; Morton *et al.* 1995; Salzman 2005) to better align on-farm decision-making with public-good outcomes. Again, such insights emerge from considering farms as part of multi-scaled, social–ecological systems.

Not all ultimate drivers of ecosystem change are negative with respect to land degradation. Changing market preferences and demands can be an important positive driver, for example where consumer desire for 'green' products (Yiridoe *et al.* 2005; Forbes *et al.* 2009) encourages farmers to adopt sustainable land management practices. Producers' personal commitment to continuous improvement in environmental management and sustainable production is also an important driver of industry change. Over 100 cattle and sheep producers throughout Australia are the driving force behind Target 100, an initiative to deliver sustainable cattle and sheep farming by 2020 through 100 research, development and extension initiatives (MLA 2013).

Technology can be a positive influence on land condition, in that many recent technological advances have enabled farmers to better target management interventions with precision agriculture (Trotter *et al.* 2009; Henry *et al.* 2013) and precision pastoralism (Ash and Stafford Smith 2003; Laca 2009). Examples include sparing areas that are vulnerable to land degradation, and use of global positioning systems to target fertiliser and herbicide applications. Technological advances have also enabled the application of more environmentally sustainable management practices such as direct drilling instead of ploughing (Peigné *et al.* 2007), especially where native pastures can be direct-drilled with more productive species and simultaneously enhance the native biodiversity (i.e. pasture cropping and no-kill cropping: Millar and Badgery 2009; Norton and Reid 2013).

The drivers interact across a range of levels both spatially (farm, region, country, global) and temporally (annual, decadal, etc.; Nelson *et al.* 2006) and may interact synergistically. It is often the synergistic effects that are of most concern in terms of land degradation (Brook *et al.* 2008; Sala *et al.* 2000). For example, the impact of weeds is often worse in landscapes that have experienced greater native woody vegetation clearance than in less-affected landscapes (Didham *et al.* 2007), with remnant vegetation in highly affected landscapes being more prone to the effects of weeds irrespective of other factors.

In some situations it may not be possible to restore degraded ecosystems because they have crossed ecological and financial thresholds that are difficult to reverse (Westoby *et al.* 1989). As discussed above, the removal of deep-rooted woody vegetation has resulted in rising water tables and the increasing expression of dryland salinity in previously productive farmland (Cramer and Hobbs 2002). While planting deep-rooted native or exotic woody vegetation can address this issue in some areas, where the spatial scale of salinisation is large, reversal is not possible without substantial management inputs (Anderies *et al.* 2006). Woody weed encroachment in semi-arid NSW is an example of the system having crossed an ecological threshold. Overgrazing led to the loss of perennial grasses, which were otherwise capable of outcompeting unpalatable native shrubs. Shrub seedlings established in occasional wet periods and were not promptly burnt or outcompeted at an early age in the absence of the perennial grasses. Most woody weed species become basically indestructible to above-ground browsing, burning or slashing, and subsequently suppress grass production even in the absence of grazing (Hodgkinson and Harrington 1985; Tighe *et al.* 2009).

The cost–price squeeze

Over the past 50 years, ABARES' index of the volume of agricultural production has doubled in value, a testament both to advances made by researchers and the adoption of more productive technologies by farmers and to the significant increase in area farmed (Fig. 19.8). Over the same period, the trend in real gross cost of production has increased by a factor of 1.3 while real gross value has

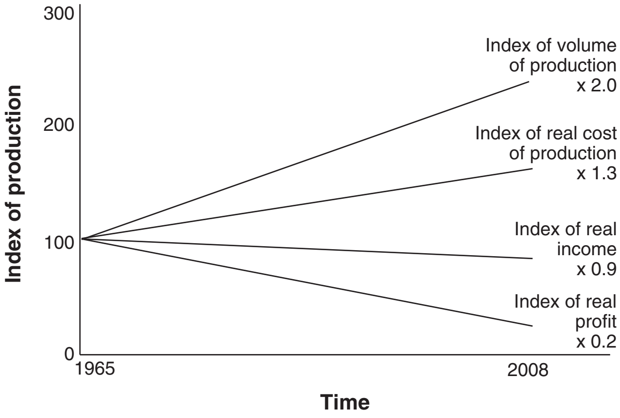


Figure 19.8: Trends in key farm performance indicators, 1965–2008. Source: Adapted from Gardiner and Reid (2010); based on ABARES data.

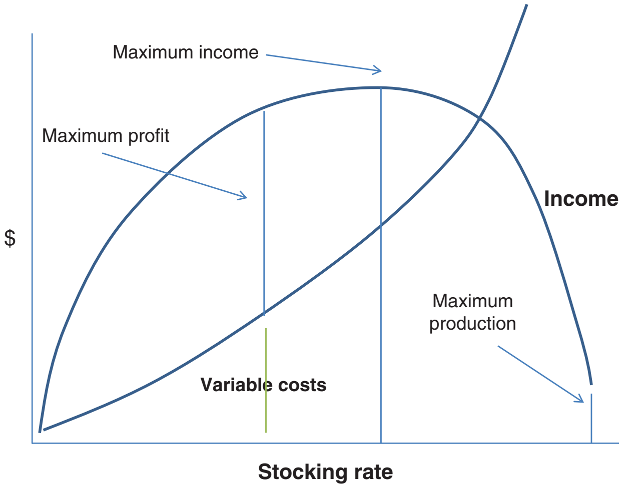


Figure 19.9: The relationship between stocking rate, variable costs, income and the points of maximum profit, maximum income and maximum production. Source: Adapted from Gardiner and Reid (2010).

fallen slightly, meaning that the real net value (and profitability per farmed hectare) has fallen by 80%. Australian farmers have been subject to deteriorating terms of trade of agriculture for at least the past 45 years. They have responded by increasing the volume of production, for instance by intensifying and increasing the efficiency of production (through improvements in genetics and nutrition) and clearing more country. However, due to falling prices, Australian farmers have not managed to maintain their real income over that time.

The response of primary producers to the cost–price squeeze in recent decades has had multiple environmental and social impacts throughout beef production social–ecological systems as well in wider society and regional Australia. Maximising production, as opposed to profit, has some socio-economic benefits at the national level (Gardiner and Reid 2010). Increasing production efficiency has a positive impact on the national accounts. If increasing efficiency lowers product prices, consumers have more spare money to spend on other goods and services (increasing consumer surplus) and the economy at large maximises total income from that sector (the sum of producer income and consumer surplus). However, increasing efficiency transfers income from producers to consumers and disadvantages regional areas. As the profitability of agriculture has declined, the economic, social and environmental cost to the sustainability of agriculture and rural areas has been measured in the deterioration of smaller regional communities (Garnaut *et al.* 2001), the rundown of on-farm natural resources (State of the Environment 2011) and a blow-out in average farm debt (Gardiner and Reid 2010). Sound environmental management is often an early casualty when graziers are hard-pressed economically (Young 1984; Young *et al.* 1984).

In response to declining terms of trade, the economically rational response at the farm level is to manage for maximum profitability rather than maximum income or production, because these three outcomes are always maximised sequentially in relation to increasing stock numbers or stocking rate: profit first, then income, then production (Fig. 19.9). However, given that all farms have deleterious environmental impacts (i.e. negative ‘externalities’) that are currently unpaid for by either producers or consumers, greater sustainability is, in fact, associated with a lower stocking rate than that associated with maximum profit (Gardiner and Reid 2010). The unpriced environmental impacts of beef production include GHG emissions, downstream water quality impacts, dryland salinity and native biodiversity decline due to grazing. To beat the cost–price squeeze, beef producers therefore need to monitor the production and profitability of their farm business using economic indicators such as those listed above, and either manage for maximum profit or reduce production a little and move in the direction of maximum sustainability and a smaller ecological footprint.

GHG emissions

Agriculture can contribute to lowering Australia’s GHG emissions by reducing direct emissions and by increasing the amount of carbon stored in farm soils and landscapes. Australian soils and forests store large quantities of carbon, somewhere between 100 and 200 times Australia’s current annual emissions. Rural land sinks can potentially store or mitigate enough GHGs to offset up to 20% or more of Australia's emissions during the next 40 years. Forest plantings are the most straightforward way to sequester carbon in rural landscapes and, along with reduced land clearing, provide the most immediate, significant and realisable carbon sequestration opportunity.

In 2012, the Australian government imposed a carbon tax on the 300 or so companies responsible for most of the nation's GHG emissions as a first step to lowering Australia's GHG pollution (Chapter 18; MLA 2012a). Agriculture has been exempted to date and the carbon tax could be reversed by a future government. However, the fact remains that global climate change fuelled by GHG emissions remains a major threat to Australia's prosperity for the foreseeable future (CSIRO/BOM 2007; Garnaut 2008).

To assist beef producers understand their environmental impact in relation to GHG pollution, life-cycle assessment protocols have been developed to quantify the GHG footprint of farm businesses (Harris and Narayanaswamy 2009). If beef producers want to mitigate their GHG emissions, two strategies for trading Australian carbon credit units (ACCUs) are available (MLA 2012a): environmental tree plantings and a reduction in high-rainfall area (>1000 mm per year) savanna burning. Undertaking environmental plantings on land of low production value is an option available to most graziers. However, other strategies not currently available to beef producers, such as commercial farm forestry and protection of native forests and revegetation, could have an equal or greater impact on on-farm carbon sequestration as well as contributing other private and public-good benefits.

Preliminary analyses of the carbon footprint of typical livestock properties in eastern Australia suggest there will be winners and losers if beef producers have to pay for their farm's GHG emissions. Eady and Ridoutt (2009) calculated that a typical beef and sheep grazing property on the northern tablelands generates 1104 t CO_2-e/year of GHG pollution. At a mid-range price of \$20/t CO_2-e (Garnaut 2008), New England graziers would face an average annual levy of \$22 000 per farm if agricultural carbon pollution were to be taxed.

If commercial beef properties want to achieve GHG neutrality through on-farm tree plantings, the area of farm that would need to be afforested would vary greatly, depending on climate and specific enterprises. For instance, Eady *et al.* (2011) assessed the overall 'cradle-to-farm gate' GHG emissions of two Queensland beef properties at Gympie (a 634-cow enterprise turning off weaner cattle, rainfall 1200 mm per year) and Arcadia Valley (a 720-cow enterprise turning off finished steers, 600 mm per year). Overall GHG emissions associated with the two enterprises were 3145 t CO_2-e/year at Gympie and 7253 t CO_2-e/year in the Arcadia Valley, with 95% and 79% of emissions on-farm and largely attributable to enteric methane emissions from cattle. The off-farm inputs associated with each operation were mainly fuel for farm vehicles and earth-moving equipment, electricity, supplementary feed, agricultural chemicals, farm services and purchased store steers at Arcadia Valley.

The ability to offset on-farm GHG emissions through reforestation was potentially manageable at Gympie but impossible in the Acardia Valley. The estimated carbon sequestration rates were 19–35 t CO_2-e/ha/year from eucalypt plantations at Gympie, but only 2–10 t CO_2-e/ha/year from brigalow regrowth, leucaena and environmental eucalypt plantings in the Arcadia Valley. Based on these estimates, the area to be reforested to offset on-farm emissions (over 30 years) would be 86–155 ha at Gympie (7–13% of the holding) but 629–4108 ha in the Arcadia Valley (9–60%). If growth rates were towards the higher end of these ranges, on-farm emissions could be offset by sequestration in timber, with minimal impact on beef production. However, at the lower end of the timber sequestration range, the required level of woody plantings would reduce carrying capacity and beef production at Arcadia Valley. The large variation in the Arcadia Valley estimates reflects the current state of knowledge regarding carbon sequestration in central Queensland, a non-traditional environment for tree planting with little research on potential growth rates.

Climate variability and exceptional circumstances policy and programs

There is strong evidence that the Australian climate has warmed by ~0.8°C since 1960, with more heatwaves and fewer frosts, more rain in north-west Australia, less rain in southern and eastern Australia, an increase in the intensity of droughts, and a 77 mm rise in sea level between 1961 and 2003 (Braganza and Church 2011). While some impacts of climate change will take many decades to unfold, it is increasingly likely that the level of global warming will exceed the 2°C threshold of 'dangerous' climate change (Peters *et al.* 2012). As temperatures rise with global warming, heatwaves, fires, floods and southern Australian droughts are all expected to become more frequent and intense in coming decades (Fig. 19.10).

Figure 19.10: The Cobar pediplain near Nymagee, western NSW, in April 2007, at the height of the millennium drought. High temperature events and droughts are likely to become more frequent and extreme in the next few decades, posing major challenges for livestock production systems. Source: N. Reid.

Snow and frost are very likely to become rarer or less intense.

Climate change will affect all sectors of the economy throughout the country, including water security and agriculture. Southern and eastern Australia's water supply reliability is expected to decline as a result of reduced rainfall and increased evaporation, affecting irrigation, domestic and industrial water use, and environmental flows. Production from cropping and livestock is projected to decline by 2030 over much of southern Australia due to increased drought and reduced availability of nutrients limiting productivity in most Australian landscapes. A 20% reduction in rainfall could reduce pasture productivity by 15% and livestock weight gain by 12%, substantially reducing farm income. There is likely to be a southward movement of pests and diseases as the southern regions warm. The forestry and plantation industries will face greater risk of fire.

The history of climatic variability and extremes in Australia means that there has been a National Drought Policy for the past two decades, seeking to build capacity to deal with climate variability in good seasons with assistance in extreme times. However, the final component of the policy, termed 'exceptional circumstances' (EC), has long been critiqued, both for the difficulty of devising equitable and realistic criteria for declaring drought (Stafford Smith and McKeon 1998) and for suppressing sensible adaptive responses (Stafford Smith 2003; Nelson *et al*. 2008). The extent and frequency of exceptionally hot years in Australia have been increasing rapidly (Hennessy *et al*. 2008). By 2010–40, the mean area of exceptionally high temperatures is likely to increase to 60–80% of each part of the continent. On average, what are currently regarded as exceptionally high temperatures are likely to occur every one to two years.

If exceptionally low rainfall years or exceptionally low soil moisture years were the sole trigger for EC declarations, the mean projections for 2010–40 indicate that more declarations would be likely, and over larger areas, in southern South Australia and Western Australia, south-west Western Australia, and Victoria and Tasmania. Under the high scenario, EC declarations would likely be triggered twice as often and over twice the area in all regions of Australia. These findings saw the end of the EC policy component and a greater focus on preparatory measures likely to enhance adaptive capacity. The framework for a new national package of drought programs to replace the existing EC arrangements has been agreed, informed by a 2008–09 National Review of Drought Policy and a two-year pilot trial of drought reform measures in Western Australia.

Many options for agriculture to adapt to climate variability are similar to existing best practice and good natural resource management, and do not require radical changes to farm operations and industries for the time being. These options can and should be prioritised as part of a 'no regrets' or win–win strategy for exceptional circumstances, because they provide immediate and ongoing benefits as well as preparing the sector for climate change. Consistent with this philosophy, sustainable beef producers should develop risk management plans for disasters such as wildfire, floods and droughts. Meat and Livestock Australia (MLA) and various state and federal agencies have a range of resources, publications, programs and services to assist landowners affected by natural disasters and exceptional circumstances. Recommendations for sustainable groundcover (e.g. 80–100%), litter (2 t DM/ha) and minimum pasture biomass (1–2 t DM/ha) targets are just as valid for maximising pasture resilience, rainfall-use efficiency and productivity and maximising business flexibility and resilience in drought (MLA 2006a,b, 2007) as in normal seasons in the medium- to high-rainfall zones. Conservative graziers who maintain this level of pasture and litter buffer in their paddocks at the end of grazing periods can make more money in severe drought than in better seasons because of their ability to produce quality livestock when prices received are high (Wright *et al*. 2004).

An innovative research and extension program in northern Australia, 'Climate Clever Beef', is being undertaken by Steven Bray and Dionne Walsh with the support of MLA to integrate climate risk, production and positive GHG- and carbon-related management outcomes. In terms of productivity and profitability, the project is working with landholder groups across northern Australia to determine and implement sustainable stocking rates and pasture spelling to improve the palatable perennial pasture base and land condition in relation to climate risk (variability and change), as well as using infrastructure to spread grazing pressure and minimise overgrazing of preferred land types. In some districts, the environmental focus is on property GHG profile and carbon sequestration. Options being investigated include reducing methane emissions through herd management (improving breeder herd efficiency and liveweight gain in younger stock) and sequestering more carbon via woody regrowth retention, appropriate savanna burning, land rehabilitation and increasing pasture cover.

PRODUCTION SYSTEMS: CASE STUDIES

This section profiles three farms, to illustrate some of the environmental issues that beef farmers have to deal with and some of the solutions that have been developed in the pursuit of sustainable social–ecological livestock production systems.

Rangelands: Woodgreen, Alice Springs

Woodgreen Station (123 000 ha), two hours drive north-east of Alice Springs, is owned and managed by Marie and Bob Purvis and their adult children. It is an example of many central Australian rangeland properties, with low erratic rainfall (annual rainfall median 251 mm, mean 302 mm; M. and B. Purvis, pers. comm.), a predominance of hard red mulga country and sandplain (86 600 ha), and relatively little fertile country (36 400 ha). The property was first selected by Bob's father for running horses in the 1920s. The permanent water in the best country led to overstocking due to a misunderstanding of carrying capacity, and the property emerged from the 1959–65 drought with 280 head of cattle and a debt exceeding the value of the station. Rather than walking off the property, Bob began to develop a management system that has become a model of sustainable rangeland management (Purvis 1986). The key features of the system include 1) a stocking rate that is sustainable through all seasons and that initially improves and then maintains pastures and groundcover through boom and bust, 2) subdivision and spelling of country, 3) landscape restoration and revegetation of eroded country, and 4) selective use of fire to manage woody encroachment on productive grazing country. The results have been remarkable in terms of economic production, ecological restoration and biodiversity conservation.

The lack of highly productive country dictated that the industry practice of maintaining a large breeding herd and turning off marketable young cattle was not feasible. Instead, the management focus shifted to quality three-year-old steers (Fig. 19.11). These animals fetch high prices and hold condition in the dry, if run on nutritious pastures. The breeding cow herd was progressively reduced from 1000 in the early 1970s to 350 by the 1990s. Additional high-quality land was purchased when an adjacent property came on the market and ~100 000 ha of the least productive part of the original property (principally spinifex sandplain) was returned to the Northern Territory government; it is now managed as a conservation reserve. Grazing management used to be based on using adjoining paddocks in pairs, with cattle spending six months in each paddock. Now, all herds use a three-paddock system and periodically each paddock is totally destocked for 12 months (Norton and Reid 2013). This overcomes the vagaries of individual paddocks being locked into either unreliable summer or winter rains for recovery. It also allows flexibility to take advantage of fresh feed resulting from scattered storms in a dry year. The strategy of reducing cattle numbers to match the carrying capacity of the land and keeping a large proportion of the station in

Figure 19.11: High-quality Woodgreen steers that are the result of excellent land and animal husbandry, including breeding and the use of station-bred sires that are well adapted to the climate and pastures of the property. These docile animals are easy to muster and fetch top weights and prices at market. Source: J. Purvis.

reserve has increased the proportion of palatable native plant species, which has had benefits for other aspects of biodiversity such as birds.

A key component of turning Woodgreen into a sustainable livestock production system involved restoring degraded areas (Bastin 1991). Reclamation of preferred grazing lands was undertaken with three objectives: 1) it was apparent that time alone would not repair the damage since one paddock had been destocked for 25 years and nothing had improved, 2) it was essential to retain rain water and sediment on the potentially productive landscapes rather than let it flow down 'gutters' (i.e. eroded shallow gullies) or into areas of woody 'weeds', and 3) where overgrazing had eliminated the palatable perennial grasses, it was essential to reintroduce forage plants. The result was the use of silt-retention banks and buffel grass. It takes five to 20 years to revegetate an eroded or scalded area, depending on seasons and soil fertility. Banks designed to capture sediment succeed because they catch the runoff and 'fines' as close to where they are shed as practicable, forming new topsoil and holding the rainfall in place. Woodgreen's banks are 100–300 m in length, with 35–50 built each year. The station now has over 1000 banks.

The role of buffel grass at Woodgreen presents a conundrum in that the species can be weedy if not managed properly. However, buffel grass produces a lot of organic litter, increasing the soil surface fertility sufficiently for desirable native plants to colonise and grow alongside it. However, the stocking rate must be geared to the survival of the palatable natives: if the stocking rate is too high, the desirable natives are eliminated. The return of the native species and grazing helps control buffel grass. In fact, it is no longer planted at Woodgreen as there is now a sufficient density of desirable native perennial grasses to colonise newly ponded areas.

The degradation on Woodgreen had led to dense shrub encroachment in the watercourses and in some of the best open woodland country. While fire is the best management tool to deal with this, the challenge is to achieve the best result with the least damage. Experience showed that frequent low-intensity fires are inappropriate as they burn only grass and leave the scrub. While high-intensity fires can burn valuable trees, they eliminate the scrub, although it can require three such fires to control woody encroachment and it may take 20 years. The key to successful management of the reinvasion of unwanted woody species is to not graze the perennial grasses out, so that there is always organic litter breaking down. If managed carefully, the perennial grasses inhibit scrub regrowth (Fig. 19.12).

Figure 19.12: Good water management through the use of ponding banks and cattle numbers kept at a stocking rate that matches the carrying capacity of the land in dry times and drought has resulted in excellent native grass regeneration at Woodgreen. Good perennial grass growth also carries the fires needed to prevent woody encroachment. Source: J. Purvis.

A final innovation has been the Purvis' own range monitoring system (Norton and Reid 2013). Bob developed a test to determine land condition anywhere on Woodgreen. In the mulga country, if more than seven species of edible grass or perennial herb are visible in any one area it means that the site is in good order (Purvis 2004). Only five species means that the site is at its lower limit, and three species or fewer means the site is degraded. If the best fattening country has 10 or more edible species visible from the one spot, it is in good order. At seven species the site is at its lower limit, and three or fewer means it is degraded. Bob's experience is that when both the hard red mulga country and the best fattening country are in good order, then other living things such as the native bird community are active and healthy.

High-rainfall sown pastures: Gerri, Ben Lomond

The late Graham Munsie's beef cattle trading and breeding business near Ben Lomond in northern NSW exemplifies the simplicity of decision points required to sustain a profitable operation and productive pastures, based on close observation and monitoring of pasture and livestock performance over several decades (Gardiner and Reid 2010; B. Gardiner, pers. comm.). Graham died in 2010 but he managed the family property, Gerri, after his father purchased it in 1945. The 800 ha property of fertile basalt country straddling the Great Dividing Range receives an average 1000 mm of rainfall per annum. Woody vegetation is sparse at Gerri as a result of eucalypt dieback (Fig. 19.6) and is largely limited to scattered mature white gums in some of the paddocks. The property was initially used to sow 4 ha of field peas every week in the growing season. When the local cannery closed in the early 1950s, the arable 650 ha portion of the property was sown to phalaris–white clover pasture and South Australian wethers brought in to produce wool. Obtaining shearers who were willing to shear large sheep became difficult in the late 1960s, so Graham changed to trading and breeding beef cattle, which continued until his death.

Graham ran up to 1000 steers and 150 breeders on Gerri in a good season (Gardiner and Reid 2010). If the seasons were kind, his preferred operation was to purchase weaner steers in March–April from several local herds and sell them on the young steer market in January–February the following year (B. Gardiner, pers. comm.). However, when rainfall was irregular, Graham had three key decision rules for selling steers, based on decades of monitoring of pasture levels and livestock condition, so as to not overgraze and degrade the pastures on Gerri.

1. If rainfall in March was less than average, he sold a third of the steers, because he knew it would be difficult to maintain full stocking rate through the winter.
2. If October rainfall was less than average, he immediately sold a third of the steer herd because it meant that carrying a full complement of livestock across the summer could prove difficult.
3. If pasture consumption exceeded pasture production, a third of the trade herd was immediately sold. Unlike many northern tablelands properties, where pasture productivity declines annually to almost zero in midwinter, Graham's retention of a substantial bulk of both pasture and litter across the property meant that this decision rule was implemented only infrequently at Gerri.

Steers were purchased whenever seasonal conditions permitted. Consequently, Graham ran twice as many stock as the district average in good seasons, put 450–500 kg on young 250–300 kg steers over an 11-month period, and didn't have to renovate his sown pastures in 50 years. He firmly believed that a person should have to do things only once, if at all possible. In fact, in good seasons, he often harvested phalaris seed from his paddocks and used his woolshed to dry the seed before sale.

Graham's approach to grazing management was what he called 'flip-flop' grazing. Each mob was run in a pair of paddocks (~40 ha each), two weeks in, two weeks out, then back again. He could tell from the condition of the stock whether pasture consumption exceeded pasture growth, and always maintained a reserve of 1.0–1.5 t/ha of green dry matter. Bruce Gardiner (pers. comm.) was one of the judges that awarded the regional Landcare prize for best farm to Graham in the late 2000s. At that time, phalaris and white clover still dominated the sown pastures but perhaps 20 additional pasture species, including many palatable natives, had infiltrated as well, including bromes and ryegrass in winter, yearlong-green tussock poa and microlaena, and summer-active red grass, paspalum, kangaroo grass, native sorghum and bluegrass.

Graham's approach to innovation and adoption of new technology was interesting. He would trial new ideas on the farm with a treated area and a control area for about five years, keeping records to determine whether the innovation was cost-effective. The annual application of lime was trialled and found wanting, as was the development of a keyline water system across ~100 ha of the property. About 110 small dams water the property but Graham deduced that extending the keyline system across the rest of the farm was not warranted. On the other hand, alternate annual applications of 125 kg/ha of single superphosphate and gypsum were shown to be economic and became a feature of pasture management at Gerri.

Tropical savanna: Trafalgar, Charters Towers

The semi-arid tropics extending from Queensland across northern Australia are an important and distinctive part of the Australian beef industry. The environment of Trafalgar Station, a 33 000 ha property 56 km south-west of Charters Towers, inland from Townsville, Qld, is typical of the tropical savanna beef production systems (Landsberg *et al.* 1998; Landsberg n.d.). Long-term mean annual rainfall is 647 mm but with high year-to-year variation (R. Landsberg, pers. comm.). The property comprises about one-quarter blackwood and gidgee scrub and three-quarters open box and ironbark savanna woodland. The dominant native grasses are perennial and palatable, including desert and Queensland bluegrass, black spear grass, kangaroo grass and golden beard grass. Undesirable wiregrasses and white spear grass are also widespread. Selective pasture development has been important since the 1960s, with timber clearing and establishment of introduced pasture species leading to more productive pastures capable of higher stocking rates and better individual animal performance. Some 3500 ha of box, ironbark, blackwood and gidgee country have been cleared and oversown to buffel and urochloa grasses. Some 8000 ha have also been oversown with seca and verano stylos. Stylos fix nitrogen (N) and lessen the impact of declining pasture value at the end of the dry season because of higher soil N. They are also valuable protein sources as fodder.

The key elements of the property management and grazing strategy of owner–managers, Roger and Jenny Landsberg, and their children, Kate and Bernie, include conservative stocking, paddock spelling, fire, weed management, selective pasture development, and a focus on livestock genetics (Landsberg *et al.* 1998; Landsberg n.d.; R. Landsberg, pers. comm.).

In common with many other northern Australian properties, sheep were replaced with unsustainably high stocking rates of cattle in the late 19th century. Stocking rates declined through the first half of the 20th century when recurring droughts saw herd numbers fluctuate markedly between wet and dry periods, but with total numbers averaging around 3000 head. In the late 1950s and early 1960s, Brahman cattle replaced the earlier breeds, which, coupled with the introduction of urea supplementations, saw a marked increase in animal productivity. The 1970s were marked by poor beef prices and, together with the change to Brahman genetics, good rainfall and more intensive management, the herd increased to 5000 animals by the late 1970s.

The ramifications of high animal numbers and overgrazing, especially in dry years, became apparent in the 1980s. At this time, and similar to much of northern Queensland, grazing lands began to deteriorate, with an increase in exotic woody weeds as well as native woody regrowth, marked declines in the cover of native perennial grasses, soil erosion and, in places where inappropriate tree clearance had been undertaken, salinity problems (Fig. 19.13). On Trafalgar, three different drought strategies were tried but none of them addressed the underlying land degradation problems (Landsberg *et al.* 1998). In the last of the three droughts (1987–88), a feeding program was initially successful in that animals were carried through until relief rains arrived in early 1988, but a lack of follow-up rain and nil pasture growth resulted in 60% of the herd being sold. This prompted a complete rethink of how the property was being managed.

It was apparent that just waiting for ‘good seasons’ to return in the hope that nature would repair things was not a realistic option. Instead, longer-term planning coupled with realistic goal-setting and a focus on economic and environmental sustainability were essential for the long-term viability of the property. The decision was made at the outset not to restock the property but rather to let pastures regenerate with the significant reduction in grazing pressure. This decision was backed up by simulation modelling, which showed that a sustainable cattle herd on Trafalgar was around 3000 (similar to that through the first half of the 20th century). This decision proved wise because adjacent properties that had retained much higher stock numbers through good seasons in 1989 and 1990 were seriously affected by the extended drought from 1992–96. While pasture productivity initially recovered on those properties, the perennial native grasses did not and the properties were unable to support high cattle numbers under drought conditions. In contrast, deliberate pasture spelling on Trafalgar resulted in recovery of pasture composition and productivity, which ensured greater resilience through drought.

Figure 19.13: Cattle in tropical savanna near Charters Towers, Qld. As at June 2013 the northern beef industry was in crisis due to drought, loss of overseas markets, falling prices and excessive livestock numbers. A similar combination of calamitous events was the impetus for the Landsbergs to develop their sustainable beef production system at Trafalgar in the late 1980s and early 1990s. Comparable responses are required throughout the northern industry to avoid socio-economic and environmental disaster. Source: N. Reid.

The new system at Trafalgar was based on the management of three key components of the property: cattle, pasture and finances. The aim of cattle management was to increase the productivity and improve profitability while still maintaining around 3000 head. This required a better understanding of potential markets and the use of genetics and supplement to ensure that animals met market specifications. Limousin sires helped produce heavier animals with better meat quality attractive to the export trade, while mating some of the Brahman–Limousin cows with Brangus bulls produced heifers and steers that attracted good prices in local markets. Stringent culling of dry heifers (after mating at two years) and cows resulted in earlier calving and a fertile breeder herd. The bulls were initially run all year with the cows, but controlled mating was progressively introduced from the early 1990s.

Today, the property enterprise is still primarily a Brahman-based commercial beef breeding and fattening operation (R. Landsberg, pers. comm.). The Senepol breed is being used to infuse the poll gene through the herd, although Limousin and Brangus genetics are still strong in the commercial herd. A commercial breeder herd of 1200 and a stud Brahman stud of 200 are kept fairly static so as to maintain a sustainable total herd number of 3500–4000 adult equivalents (AE). The breeder herd is control-mated for four months between November and April (or October–April for heifers). After pregnancy diagnosis in May, all non-pregnant females are culled for sale. This practice has three main outcomes: 1) it emphasises selection pressure for fertile females, 2) it removes non-productive animals (i.e. saves grass), and 3) it creates extra cash-flow.

Cattle numbers have fluctuated in recent years (2005–10), between 3035 AE in 2006 and 4285 AE in 2011, as has gross margin per AE ($139–235) and per hectare ($19–25). The fluctuating gross margin is directly attributable to the seasonal effect on production and changes in herd structure. For example, when rainfall is spread throughout the year and pasture quality remains high, supplementation and production costs remain low while meat quality and prices received are high. But if rainfall is low or confined to the wet season and the resulting pasture quality is low, supplementation costs are high while meat quality and prices are low and more variable. Flexibility in marketing remains critical, as different markets vary through time.

Pasture management involves three key activities: regular wet-season spelling, weed management and introduced pasture development. About 20% of Trafalgar is spelled each summer, the primary purpose being to improve the vigour and maintenance of desired perennial grasses for consistent supply across seasons (Ash *et al.* 2002; Orr *et al.* 1991). This strategy has helped maintain a much higher cover of native perennial grasses on Trafalgar than on adjacent properties, with flow-on benefits for erosion control and as a buffer against drought. Spelling also allows fuel build-up for burning.

Fire has been a feature of three generations of Landsberg management on Trafalgar to regenerate moribund pasture, control exotic and native weeds and reduce the recruitment of native timber seedlings. About 3000 ha is burnt annually when conditions permit. Fires range in intensity and timing from low-intensity burns for moribund pasture replacement and wildfire mitigation late in the wet season to high intensity for woody weed (e.g. currant bush, flannel weed, rubber vine) and eucalypt regrowth management in the late dry season. The timing of burns is critical, as burning under the wrong conditions wastes fuel (feed) and money (in preparation and implementation) and doesn't achieve desired goals. Good post-fire management is essential, with stock excluded until groundcover is well established.

Introduced pasture development involves oversowing stylos and grasses (buffel and urochloas) into the ash bed three to four weeks after a fire and before the first rains. Pasture improvement usually occurs in small areas where gidgee and blackwood scrub has been cleared, as pasture does best in these areas and there are minimal suckering issues. However, care is taken not to clear water intake areas. Widespread clearance of woody vegetation is no longer undertaken because of cost and the long-term ecological implications, especially the threat of salinisation and negative impacts on native biodiversity.

The third key component of management on Trafalgar is financial accountability. Close monitoring of all aspects of the accounts, including regular financial forecasting, means that management changes can be made before problems escalate. For more than 10 years, the Southern Oscillation Index and other climate forecasting tools have been used to help plan herd management decisions. These tools usually become reliable enough from about August–September for decision-making. If the outlook for the next wet season is a <50% chance of exceeding the mean rainfall, cattle are sold in September to reduce herd size before a seasonally induced market downturn. Conversely, if the outlook looks favourable or a La Niña event is likely, cattle are purchased while prices are low at the end of the dry before demand for store stock increases during the wet season.

Roger emphasises that the critical factors in the successful management of Trafalgar were a willingness to 'accept the need for change, to develop new philosophies and operating principles, and to implement appropriate strategies and tactics to bring about this change'. Willingness to change has had profound management implications, including a conservative stocking policy, regular spelling, breeding and nutritional programs designed to produce cattle for a range of markets, and long-term financial planning. More sustainable management has improved herd productivity through higher branding percentages (more calves from less cows) and earlier turnoff age in slaughter cattle. This has reduced CO_2-equivalent emissions by an estimated 46% since 1987, based on the reduction in enteric fermentation (E. Charmley and B. Shepherd, pers. comm.). Scientific studies have indicated higher than normal flora and fauna biodiversity values, including rare and threatened species of small native mammals. Land condition is excellent and it provides high-quality wildlife habitat, high-quality fodder for native grazing animals and high resilience to climate variability. Profitability has increased due to lower input costs and improved beef quality.

Roger believes that, as long as these management strategies are maintained and improved, Trafalgar will remain economically viable and ecologically sustainable for the foreseeable future.

Case study synthesis

Two common themes run through the management systems in the three case studies reviewed here: a focus on conservative (light to moderate) stocking rates linked to a sustainable forage supply, and a focus on maximising profit and achieving high returns per head for profitable production rather than maximising income or output. Both themes highlight the resilience and ecosystem stewardship credentials of these case study properties. While each property addresses the themes in different ways, the overall approach and the outcomes achieved are similar. The properties are prime examples of sustainable social–ecological livestock production systems. They highlight approaches that can be adopted by other beef producers to build economic and ecological resilience into grazing enterprises and to practise ecosystem stewardship.

In all three case studies, the importance of a stocking rate and pasture spelling strategy that sustain and improve the pasture resource and do not damage pasture or the soil resource when rainfall is scarce is fundamental to success. Both Woodgreen and Trafalgar have worked out a sustainable stocking rate that enables all livestock to be carried through drought periods. At Gerri, the approach differs – defined rainfall triggers are used to make decisions about selling livestock. Woodgreen and Trafalgar use substantial periods of spelling to ensure that pastures are renewed and able to sustain the more palatable perennial native grasses. At Gerri, spelling is much shorter but the objective is similar, especially when coupled with the rainfall-based triggers dictating stock numbers in order to retain sufficient residual pasture biomass after grazing periods. In all three cases, the underlying approach is to match stocking with forage production during dry periods, with the differences between the properties reflecting the on-farm breeding enterprises at Woodgreen and Trafalgar as opposed to the trading operation at Gerri.

In very different ways, the three properties have all focused on maximising profit and obtaining a high return per animal. At Woodgreen, where the costs associated with sending animals to distant markets are very high, maximum profit per animal is imperative and the focus is on producing high-quality heavy steers at three years. Trafalgar and Gerri take a more flexible approach to marketing, both in terms of the types of animals produced and, in the case of Gerri, the numbers of animals held at any particular time. The approach at Gerri is to produce the best possible product during good seasons and to offload animals at the onset of dry conditions before the decline in market prices, to help sustain the forage base and maintain profit. At Trafalgar, finished livestock are closely tailored to the specifications of the most lucrative markets available.

In order to achieve their goals of economic and ecological sustainability, all three properties closely monitor environmental conditions, including vegetation and rainfall. They are innovative and adaptive in their property management, whether it be the ongoing adaptation and use of banks to trap sediment and infiltrate water on potentially productive land at Woodgreen, the strategic use of fire at Woodgreen and Trafalgar, or the careful comparison and analysis of the benefits and costs of innovations and the use of rainfall triggers to conserve the pasture resource and maximise returns at Gerri.

FUTURE OUTLOOK

Despite the cost–price squeeze confronting Australian beef producers and the increasing pace of change and turbulence in their decision-making environment, there are at least two reasons to be optimistic about the medium-term future of beef production and thus the quality of beef producers' environmental management (Gardiner and Reid 2010). First, the rainfall-use efficiency of most broadacre farms in the medium- and high-rainfall zones is well below targets that can be achieved by observing the six paddock indicators of sustainable production.

Many farms convert only 20–30% of their annual rainfall into commercial farm products for sale, when 70% may be achievable. Perhaps surprisingly, rainfall is not the most limiting factor on most farms and grazing properties. On some farms, rainfall-use efficiency varies between 9% and 74% between paddocks. It follows that there are often paddocks that are not covering the variable costs of production. If producers are given the tools to identify these areas (Chapter 20), they could close the gate on them and have more money and time for other activities, or use best-management practices to improve rainfall-use efficiency in such paddocks in order to graze them profitably. It is a straightforward exercise to calculate the annual rainfall-use efficiency of each paddock on a farm. Thus, more leisure and profit are within the reach of many producers: parts of farms that cannot pay their way should be retired and a more profitable enterprise, stewardship payments (Williams and Price 2010) or *pro bono* nature conservation should be considered.

Second, many primary producers are uncertain about the difference between the concepts of profit, income and production (Fig. 19.9), commonly using the terms interchangeably (Gardiner and Reid 2010). Even when the concepts are understood, they are often thought to move in the same direction: that is, more production equals more income equals more profit. Thus, many producers are more concerned about maximising production than profit (O'Reagain and Bushell 2011). Most farmers don't undertake regular financial forecasting, lack robust monitoring systems or don't use simple financial indicators that allow them to make rational production decisions and move their farm business in the direction of increasing profitability and sustainability. These paddock skills and farm office tools are readily extended, so increased profits and better land management are within the grasp of most producers (Nelson and Robinson 2009).

There are, however, some wicked problems that have the potential to adversely affect Australian livestock producers in the future and for which solutions are not yet apparent – assuming they exist. The Australian beef industry is dependent on non-renewable cheap fossil fuels and, in the medium- to high-rainfall zone, superphosphate. Neither is limitless and it is difficult to imagine how broadacre agriculture will adapt to a world without either. New technologies such as walk-over weighing and cameras will assist in reducing vehicular costs and fossil fuel dependency in some situations. Technological optimists argue that as these resources become increasingly scarce and expensive, rising prices will make substitute resources and technologies increasingly competitive and attractive, ultimately replacing cheap fossil energy and guano as fundamental inputs in the Australian beef industry. Part of the problem is that there are no cheap alternatives without their own attendant problems, whether of cost, technological limitations or environmental hazards.

As Chow *et al.* (2003) wrote:

> Will the world make a transition to alternative, more renewable sources of energy? The simple answer is yes, if only because, in time, supplies of fossil fuels will become too costly. For the next 25 to 50 years, however, this seems not to be a likely prospect. With energy choices driven by relative prices, fossil fuels will dominate energy use for many years to come. These fuels remain relatively inexpensive, and they are supported by a very broad and long-lived infrastructure of mines, wells, pipelines, refineries, gas stations, power plants, rail lines, tankers, and vehicles. Very powerful political constituencies exist worldwide to ensure that investments in this infrastructure are protected.
>
> If fossil fuel depletion occurs more rapidly than we expect, or if governments enact policies that artificially increase fossil fuel prices, renewables and alternative energy sources may come online more quickly. The requisite political will and financial support to enact such changes will occur only when societies and their governments decide that the benefits of fossil fuel consumption do not make up for the negative effects on environmental health and human welfare of fossil fuel dependence.

An equally troubling, wicked problem for the beef industry is the ecological inefficiency of meat (secondary) production compared to plant (primary) production. Energy and matter transfers between trophic levels in ecosystems are notoriously inefficient (Krebs 2009), so the costs of producing 1 kg of beef in terms of energy, land, water-use and GHG emissions are about an order of magnitude greater than an equivalently nutritious kilogram of plant protein. As the world population reaches over 9 billion people, global food production will have to double to meet demand. Given that almost half the planetary land surface is already devoted to food production, and that some of that land base is losing rather than increasing productivity, coupled with the increasing scarcity of fundamental inputs to current agricultural production just mentioned, it becomes as much an ethical as an economic question as to whether meat consumption will be morally justifiable in terms of the conservation and sharing of scarce resources in a future world. Market forces will continue to dictate that food production is driven by the affluent, whereas humanitarian need will advocate a voluntary switch to plant-based food production. However, in many parts of the world, including the pastoral zone of Australia, the availability of non-arable land suited to beef production will result in perfect alignment of these economic and ethical drivers. The dual pressures will only increase the requirement for Australian beef producers to develop sustainable, resilient production systems to help meet the global demand for food and fibre.

Notwithstanding these considerations, the massive projected increase in the world's middle class in the next few decades and the concomitant increase in meat consumption and demand for luxury products such as leather and wool will ensure that beef and other livestock production systems continue to be a major component of Australian agriculture in the medium term. The recognition that beef enterprises are complex adaptive systems provides producers with the opportunity to anticipate future challenges. By taking a resilience-based approach to land management, beef producers will be able to continue to produce high-value products while sustaining the social–ecological systems that such production depends on. The key is being prepared and willing to adapt management in response to new situations.

Many of the land management practices that are necessary to ensure that beef production systems continue to deliver a wide range of ecosystem services are now commonplace (Fig. 19.14). These include: revegetation and land rehabilitation; fencing of woodland remnants, riparian zones and to land type; use of contour and water-spreading banks to infiltrate water and trap sediment; sustainable grazing management practices including pasture spelling and low to moderate stocking rates set at the long-term carrying capacity; reliance on a perennial rather than annual forage base where possible; maintaining sufficient groundcover, litter and residual pasture biomass after grazing; and use of fire to maintain an appropriate woody–herbaceous balance. These and other on-ground initiatives enhance livestock production and make beef enterprises more resilient, while also delivering positive outcomes for carbon sequestration, erosion, downstream water quality and biodiversity conservation. However, perhaps the most fundamental action a beef farmer can undertake to ensure system resilience is to graze conservatively (O'Reagain *et al.* 2009; McCosker *et al.* 2010; O'Reagain and Bushell 2011) – to ensure that stocking rates are set at a level that is sustainable through prolonged drought or a period of high costs. Stock numbers can be higher when feed is abundant but resilient social–ecological beef production systems require early trigger points to reduce stock as conditions start to deteriorate, in order to avoid damaging the natural resource base and attendant biodiversity.

Figure 19.14: Water-spreading banks are an excellent example of a sustainable management intervention for semi-arid and arid livestock production. They slow runoff and enhance infiltration. The bank holds up water on the upslope (left-hand) side, releasing it through gaps in the bank to pond in the borrow pit on the downslope side, from which it is slowly released along the length of the borrow pit. This example is from Florida in semi-arid western NSW (Smith *et al.* 2013). Source: N. Reid.

CONCLUSION

Progress towards alleviating poverty and improving human well-being has come at the expense of many of the world's natural ecosystems and ecosystem services upon which humankind depends. Ecosystem stewardship in the beef industry has never been more important for maintaining the Earth's life-support system and protecting global biodiversity. This chapter has considered beef enterprises and the beef cattle industry as examples of complex, adaptive, social–ecological systems in order to better understand, anticipate and manage the many wicked problems that confront livestock producers. Sustainable beef enterprises must strive to achieve a wide range of social, economic, environmental and managerial targets. Despite a poor report card globally and in parts of

Australia from time to time, excellent case studies of sustainable beef production systems point the way to sustainable production in both the high-rainfall and pastoral zones. Simple paddock and office indicators are available to manage conservatively, maximise the rainfall-use efficiency of production, and maximise productivity and profitability, meaning that the short- to medium-term prognosis of the meat and livestock industries is positive. However, global population pressures, GHG emissions and associated climate change, the eventual diminution of cheap fossil fuels and superphosphate, and the planetary loss of biodiversity cloud the longer-term future.

ACKNOWLEDGEMENTS

We are indebted to Bob, Mahri and Jim Purvis, Bruce Gardiner and Roger Landsberg for sharing their extraordinary knowledge, wisdom and experience. The comments of David Cottle, Lewis Kahn and an anonymous reviewer greatly improved the quality of the chapter. ABARES data on the size and distribution of the Australian beef herd at 30 June 2012 were sourced from the Department of Agriculture, Fisheries and Forestry (<http://abares.win.hostaway.net.au/ame/agsurf/agsurf.asp>).

REFERENCES

ABARES (2013) *Australian Farm Survey Results 2010–11 to 2012–13.* Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

ABS (2002) *Salinity on Australian Farms.* Australian Bureau of Statistics, Canberra.

ABS (2005) *2005 Year Book Australia*. No. 87, Cat. No. 1301.0. Australian Bureau of Statistics, Canberra.

Anderies JM, Ryan P, Walker BH (2006) Loss of resilience, crisis, and institutional change: lessons from an intensive agricultural system in south-eastern Australia. *Ecosystems* **9**, 865–878. doi:10.1007/s10021-006-0017-1.

ANRA (2009) *Agriculture – Beef Industry – Australia. Australian Natural Resources Atlas.* Department of Sustainability, Environment, Water, Population and Communities, Canberra.

APSC (2007) *Tackling Wicked Problems: A Public Policy Perspective.* Australian Public Services Commission, Canberra.

Ash A, Stafford Smith M (2003) Pastoralism in tropical rangelands: seizing the opportunity to change. *Rangeland Journal* **25**, 113–127. doi:10.1071/RJ03010.

Ash AJ, Ksiksi T, Corfield J (2002) *The Ecograze Project: Developing Guidelines to Better Manage Grazing Country.* CSIRO Sustainable Ecosystems, Townsville.

Bastin G (1991) Rangeland reclamation on Atartinga station, central Australia. *Australian Journal of Soil and Water Conservation* **4**, 18–25.

Bradsen J (1988) Soil conservation legislation in Australia. Report to the National Soil Conservation Program. University of Adelaide, Adelaide.

Braganza K, Church JA (2011) Observations of global and Australian climate. In *Climate Change: Science and Solutions for Australia* (Eds H Cleugh, M Stafford Smith, M Battaglia and P Graham) pp. 1–14. CSIRO Publishing, Melbourne.

Brook BW, Sodhi NS, Bradshaw CJA (2008) Synergies among extinction drivers under global change. *Trends in Ecology and Evolution* **23**, 453–460. doi:10.1016/j.tree.2008.03.011.

Butterfield J, Bingham S, Savory A (2006) *Holistic Management Handbook*. Island Press, Washington.

Cash DW, Adhger WN, Berkes F, Garden P, Lebel L, Olsson P, Pritchard L, Young O (2006) Scale and cross-scale dynamics: governance and information in a multi-level world. Ecology and Society **11**, 8. <http://www.ecologyandsociety.org/vol11/iss2/art8/>.

Chapin FS, Folke C, Kofinas GP (2009) A framework for understanding change. In *Principles of Ecosystem Stewardship: Resilience-based Natural Resource Management in a Changing World.* (Eds FS Chapin, GP Kofinas and C Folke) pp. 3–28. Springer, New York.

Chichilnisky G, Heal GM (1998) Economic returns from the biosphere. *Nature* **391**, 629–630. doi:10.1038/35481.

Chow J, Kopp RJ, Portney PR (2003) Energy resources and global development. *Science* **302**, 1528–1531. doi:10.1126/science.1091939.

Costanza R, d'Arge R, de Groot R, Farberk S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. *Nature* **387**, 253–260. doi:10.1038/387253a0.

Cramer VA, Hobbs RJ (2002) Ecological consequences of altered hydrological regimes in fragmented ecosystems in southern Australia: impacts and possible management responses. *Austral Ecology* **27**, 546–564. doi:10.1046/j.1442-9993.2002.01215.x.

CSIRO/BOM (2007) Climate Change in Australia. Technical Report 2007. CSIRO/Bureau of Meteorology, Melbourne.

CWWCMA (2010) *Managing Native Scrub to Rehabilitate Native Pastures and Open Woodlands: A Best Management Practice Guide for the Central West and Western Catchments.* Central West and Western Catchment Management Authorities, Wellington and Cobar, NSW.

Dasgupta P (2001) *Human Well-being and the Natural Environment.* Oxford University Press, Oxford.

Didham RK, Tylianakis JM, Gemmell NJ, Rand TA, Ewers RM (2007) Interactive effects of habitat modification and species invasion on native species decline. *Trends in Ecology and Evolution* **22**, 489–496. doi:10.1016/j.tree.2007.07.001.

Dregne HE (1983) *Desertification of Arid Lands.* Harwood Academic, Chur.

Eady S, Ridoutt B (2009) Setting reporting periods, allocation methods and system boundaries for Australian agricultural life cycle assessment. In *Sustainability Tools for a New Climate: Proceedings of the 6th Australian Conference on Life*

Cycle Assessment, 16–19 February. Australian Life Cycle Assessment Society, Melbourne.

Eady S, Viner J, MacDonnell J (2011) On-farm greenhouse gas emissions and water use: case studies in the Queensland beef industry. *Animal Production Science* **51**, 667–681. doi:10.1071/AN11030.

Ecker S, Thompson L, Kancans R, Stenekes N, Mallawaarachchi T (2013) *Drivers of Practice Change in Land Management in Australian Agriculture: Results of a National Farm Survey.* Department of Agriculture, Fisheries and Forestry, Canberra.

Fernández R, Archer ERM, Ash AJ, Dowlatabadi H, Hiernaux PHY, Reynolds JF, Vogel CH, Walker BH, Wiegand T (2002) Degradation and recovery in socio-ecological systems: a view from the household/farm level. In *Global Desertification: Do Humans Cause Deserts?* (Eds JF Reynolds and DM Stafford Smith) pp. 297–323. Dahlem University Press, Berlin.

Foran BD, Stafford Smith DM (1991) Risk, biology and drought management strategies for cattle stations in Central Australia. *Journal of Environmental Management* **33**, 17–33. doi:10.1016/S0301-4797(05)80045-3.

Forbes SL, Cohen DA, Cullen R, Wratten SD, Fountain J (2009) Consumer attitudes regarding environmentally sustainable wine: an exploratory study of the New Zealand marketplace. *Journal of Cleaner Production* **17**, 1195–1199. doi:10.1016/j.jclepro.2009.04.008.

Gardiner B, Reid N (2010) Sustainable livestock production. In *International Sheep and Wool Handbook.* (Ed D Cottle) pp. 445–471. Nottingham University Press, Nottingham.

Garnaut R (2008) *The Garnaut Climate Change Review: Final Report.* Cambridge University Press, Melbourne.

Garnaut J, Connell P, Lindsay R, Rodriguez V (2001) Country Australia: influences on employment and population growth. Research Report 2001.1. Australian Bureau of Agricultural and Resource Economics, Canberra.

Griggs D, Stafford Smith M, Gaffney O, Rockstrom J, Ohman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I (2013) Sustainable development goals for people and planet. *Nature* **495**, 305–307. doi:10.1038/495305a.

Gunderson LH (2000) Ecological resilience: in theory and application. *Annual Review of Ecology and Systematics* **31**, 425–439. doi:10.1146/annurev.ecolsys.31.1.425.

Harrington GN, Mills DMD, Pressland AJ, Hodgkinson KC (1984) Semi-arid woodlands. In *Management of Australia's Rangelands* (Eds GN Harrington, AD Wilson and MD Young) pp. 189–207. CSIRO Publishing, Melbourne.

Harris S, Narayanaswamy V (2009) *Life Cycle Assessment Methodology for Australian Rural Industries.* Publication No. 09/028. Rural Industries Research and Development Corporation, Canberra.

Hennessy K, Fawcett R, Kirono D, Mpelasoka F, Jones D, Bathols J, Whetton P, Stafford Smith M, Howden M, Mitchell C, Plummer N (2008) *An Assessment of the Impact of Climate Change on the Nature and Frequency of Exceptional Climatic Events*. Bureau of Meteorology, Canberra.

Henry D, Shovelton J, de Fegely C, Manning M, Beattie L, Trotter M (2013) Potential for information technologies to improve decision-making for the southern livestock industries: Final Report. Meat and Livestock Australia, Sydney.

Hilderbrand RH, Watts AC, Randle A (2005) The myths of restoration ecology. *Ecology and Society 10*, 19. <http://www.ecologyandsociety.org/vol10/iss1/art19/>.

Hobbs RJ, Norton DA (1996) Towards a conceptual framework for restoration ecology. *Restoration Ecology* **4**, 93–110. doi:10.1111/j.1526-100X.1996.tb00112.x.

Hodgkinson KC, Harrington GN (1985) The case for prescribed burning to control shrubs in eastern semi-arid woodlands. *Australian Rangeland Journal* **7**, 64–74. doi:10.1071/RJ9850064.

Holling CS (1973) Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* **4**, 1–23. doi:10.1146/annurev.es.04.110173.000245.

Holling CS (1978) *Adaptive Environmental Assessment and Management.* Wiley, Chichester.

Holling CS, Meffe GK (1996) Command and control and the pathology of natural resource management. *Conservation Biology* **10**, 328–337. doi:10.1046/j.1523-1739.1996.10020328.x.

Hunt LP (2008) Safe pasture utilisation rates as a grazing management tool in extensively grazed tropical savannas of northern Australia. *Rangeland Journal* **30**, 305–315. doi:10.1071/RJ07058.

IC (1998) *A Full Repairing Lease: Inquiry into Ecologically Sustainable Land Management.* Industry Commission, Canberra.

James CD, Stafford Smith DM, Landsberg J, Fisher A, Tynan R, Maconochie J, Woinarski JCZ (2000) Biograze: melding off-reserve conservation of native species with animal production in Australian rangelands. In *Nature Conservation 5: Managing the Matrix – Conservation Outside Nature Reserves.* (Eds D Saunders and J Craig) pp. 290–300. Surrey Beatty and Sons, Sydney.

Kemp DR, Michalk DL (Eds) (2011) *Development of Sustainable Livestock Systems on Grasslands in North-Western China.* ACIAR Proceedings No. 134. Australian Centre for International Agricultural Research, Canberra.

Krebs CJ (2009) *Ecology: The Experimental Analysis of Distribution and Abundance.* 6th edn. Benjamin Cummings, San Francisco.

Laca EA (2009) Precision livestock production: tools and concepts. *Revista Brasileira de Zootecnia – Brazilian Journal of Animal Science* **38**, 123–132.

Landsberg R (no date) *Fire as a Management Tool in the Semi-arid Tropics: A Case Study from Charters Towers, Queensland.* Fire and Weed Management Case Study. Tropical Savannas Cooperative Research Centre, Darwin. <http://savanna.cdu.edu.au/publications/savanna_prime_notes.html>.

Landsberg RG, Ash AJ, Sheperd RK, McKeon GM (1998) Learning from history to survive in the future: management evolution on Trafalgar station, north-east Queensland. *Rangeland Journal* **20**, 104–118. doi:10.1071/RJ9980104.

Lardner HA, Kirychuk BD, Braul L, Willms WD, Yarotski J (2005) The effect of water quality on cattle performance on pasture. *Australian Journal of Agricultural Research* **56**, 97–104. doi:10.1071/AR04086.

Lesslie R, Mewett J (2013) *Land Use and Management: The Australian Context*. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Lodge GM, Whalley RDB (1989) Native and natural pastures on the northern slopes and tablelands of New South Wales. Technical Bulletin No. 35. NSW Department of Agriculture and Fisheries, Sydney.

Ludwig JA, Tongway DJ (1995) Spatial organisation of landscapes and its function in semi-arid woodlands, Australia. *Landscape Ecology* **10**, 51–63. doi:10.1007/BF00158553.

Malcolm B, Sale P, Leury B, Barlow S (2009) *Agriculture in Australia: An Introduction*. 2nd edn. Oxford University Press, Melbourne.

Mason W, Warn L, Cahill G (2003) *Towards Sustainable Grazing: The Professional Producers Guide*. Meat and Livestock Australia, Sydney.

Massy C (2012) *Breaking the Sheep's Back*. University of Queensland Press, Brisbane.

Mattison EHA, Norris K (2005) Bridging the gaps between agricultural policy, land-use and biodiversity. *Trends in Ecology and Evolution* **20**, 610–616. doi:10.1016/j.tree.2005.08.011.

McCosker T, McLean D, Holmes P (2010) Northern beef situation analysis 2009. Final Report, Project No. B.NBP.0518. Meat and Livestock Australia, Sydney.

McIntyre S, McIvor JG, Heard KM (2004) *Managing and Conserving Grassy Woodlands*. CSIRO Publishing, Melbourne.

McIvor J, Bray S, Grice T, Hunt L (2010) Grazing management guidelines for northern Australia: scientific rationale and justification. Final Report, Project No. B.NBP.0579. Meat and Livestock Australia, Sydney.

MEA (Millennium Ecosystem Assessment) (2005a) *Ecosystems and Human Well-being. Vol. 1. Current State and Trends.* Island Press, Washington.

MEA (Millennium Ecosystem Assessment) (2005b) *Ecosystems and Human Well-being. Synthesis.* Island Press, Washington.

Millar GD, Badgery WB (2009) Pasture cropping: a new approach to integrate crop and livestock farming systems. *Animal Production Science* **49**, 777–787. doi:10.1071/AN09017.

MLA (2006a) Looking after drought pastures. Tips and Tools: Feedbase and Pastures. Meat and Livestock Australia, Sydney.

MLA (2006b) Managing ground cover to reduce run-off and water loss. Tips and Tools: Natural Resource Management. Meat and Livestock Australia, Sydney.

MLA (2007) Managing weeds after drought. Tips and Tools: Natural Resource Management. Meat and Livestock Australia, Sydney.

MLA (2010) Red meat green facts: Australian red meat and the environment. Meat and Livestock Australia, Sydney.

MLA (2012a) Carbon farming initiative. Facts and Stats: Natural Resource Management. Meat and Livestock Australia, Sydney.

MLA (2012b) Kit 6 management guidelines. Biodiversity Condition Toolkit for Grazed Lands. Meat and Livestock Australia, Sydney.

MLA (2013) *Target 100*. Meat and Livestock Australia, Sydney. <http://www.target100.com.au/Home>.

Morton SR, Stafford Smith DM, Friedel MH, Griffin GF, Pickup G (1995) The stewardship of arid Australia: ecology and landscape management. *Journal of Environmental Management* **43**, 209–217. doi:10.1016/S0301-4797(95)90402-6.

Nelson BS, Robinson E (2009) Critical success factors of a whole of business extension approach for increased capacity of beef producers and improved enterprise profit and sustainability. *Rangeland Journal* **31**, 61–68. doi:10.1071/RJ08059.

Nelson GC, Bennett E, Berhe AA, Cassman K, DeFries R, Dietz T, Dobermann A, Dobson A, Janetos A, Levy M, Marco D, Nakicenovic N, O'Neill B, Norgaard R, Petschel-Held G, Ojima D, Pingali P, Watson R, Zurek M (2006) Anthropogenic drivers of ecosystem change: an overview. *Ecology and Society* **11**, 29. <http://www.ecologyandsociety.org/vol11/iss2/art29/>.

Nelson R, Howden M, Stafford Smith M (2008) Using adaptive governance to rethink the way science supports Australian drought policy. *Environmental Science and Policy* **11**, 588–601. doi:10.1016/j.envsci.2008.06.005.

NLWRA (2001) *Dryland Salinity in Australia*. National Land and Water Resources Audit, Canberra.

Noble IR, Slatyer RO (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* **43**, 5–21. doi:10.1007/BF00121013.

Norton D, Reid N (2013) *Nature and Farming: Sustaining Native Biodiversity in Agricultural Landscapes*. CSIRO Publishing, Melbourne.

O'Reagain PJ, Bushell JJ (2011) *The Wambiana Grazing Trial: Key Learnings for Sustainable and Profitable Management in a Variable Environment*. Agric.-Science Queensland, Department of Employment, Economic Development and Innovation, Brisbane.

O'Reagain PJ, Bushell JJ, Holloway C, Reid A (2009) Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science* **49**, 85–99. doi:10.1071/EA07187.

O'Reagain PJ, Bushell J, Holmes B (2011) Managing for rainfall variability: long-term profitability of different grazing strategies in a northern Australian tropical savanna. *Animal Production Science* **51**, 210–224. doi:10.1071/AN10106.

Orr DM, McKeon GM, Day KA (1991) Burning and exclosure can rehabilitate degraded black speargrass (*Heteropogon contortus*) pastures. *Tropical Grasslands* **25**, 333–336.

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, Wilkinson R (2006) Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture* **46**, 1407–1424. doi:10.1071/EA05037.

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, Wilkinson R (2011) Understanding and promoting adoption of conservation practices by rural landholders. In *Changing Land Management: Adoption of New Practices by Rural Landholders*. (Eds D Pannell and F Vanclay) pp. 11–38. CSIRO Publishing, Melbourne.

Peigné J, Ball BC, Roger-Estrada J, David C (2007) Is conservation tillage suitable for organic farming? A review. *Soil Use* *and Management* **23**, 129–144. doi:10.1111/j.1475-2743.2006.00082.x.

Peters GP, Andrew RM, Boden T, Canadell JG, Ciais P, Le Quere C, Marland G, Raupach MR, Wilson C (2012) The challenge to keep global warming below 2°C. *Nature Climate Change* **3**, 4–6. doi:10.1038/nclimate1783.

PMSEIC (1999) Dryland salinity and its impact on rural industries and the landscape. Occasional Paper No. 1. Prime Minister's Science, Engineering and Innovation Council. Department of Industry, Science and Resources, Canberra.

Purvis JR (1986) Nurture the land: my philosophies of pastoral management in central Australia. *Australian Rangeland Journal* **8**, 110–117. doi:10.1071/RJ9860110.

Purvis B (2004) Practical biodiversity. In *Living in the Outback. Proceedings of the Australian Rangeland Society 13th Biennial Conference*, 5–8 July, Alice Springs. (Eds GN Bastin, D Walsh and S Nicolson) pp. 305–306. Australian Rangeland Society, Perth.

Reid N (2000) Maintaining tree cover health in temperate pastoral landscapes. In *Balancing Conservation and Production in Grassy Landscapes*. (Eds T Barlow and R Thorburn) pp. 177–187. Environment Australia, Canberra.

Reid N (2006) How to lift wool profits and improve biodiversity. Fact Sheet 10. Land, Water and Wool Northern Tablelands Project. Southern New England Landcare/University of New England, Armidale, NSW.

Reid N, Landsberg J (2000) Tree decline in agricultural landscapes: what we stand to lose. In *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration*. (Eds RJ Hobbs and CJ Yates) pp. 127–166. Surrey Beatty, Sydney.

Reid N, Zirkler K (2006) Fauna on case study farms. Fact Sheet 6. Land, Water and Wool Northern Tablelands Project. Southern New England Landcare/University of New England, Armidale, NSW.

Sala OE, Chapin FS III, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. *Science* **287**, 1770–1774. doi:10.1126/science.287.5459.1770.

Salzman J (2005) Creating markets for ecosystem services: notes from the field. *New York University Law Review* **80**, 870–961.

Sillmann J, Roeckner E (2008) Indices for extreme events in projections of anthropogenic climate change. *Climatic Change* **86**, 83–104. doi:10.1007/s10584-007-9308-6.

Smith MD (2011) The ecological role of climate extremes; current understanding and future prospects. *Journal of Ecology* **99**, 651–655. doi:10.1111/j.1365-2745.2011.01833.x.

Smith R, Tighe M, Reid N, Briggs S, Wilson B (2013) Patch and soil characteristics of pastures with water-spreading banks and woody encroachment in semi-arid Australia. *Ecological Management and Restoration* **14**, 120–126. doi:10.1111/emr.12034.

Stafford Smith M (2003) Linking environments, decision-making and policy in handling climatic variability. In *Beyond Drought in Australia: People, Policy and Perspectives*. (Eds L Botterill and M Fisher) pp. 131–151. CSIRO Publishing: Melbourne.

Stafford Smith DM, Foran B (1992) An approach to assessing the economic risk of different drought management tactics on a South Australian pastoral sheep station. *Agricultural Systems* **39**, 83–105. doi:10.1016/0308-521X(92)90006-A.

Stafford Smith M, McAllister RRJ (2008) Managing arid zone natural resources in Australia for spatial and temporal variability: an approach from first principles. *Rangeland Journal* **30**, 15–27. doi:10.1071/RJ07052.

Stafford Smith DM, McKeon GM (1998) Assessing the historical frequency of drought events on grazing properties in Australian rangelands. *Agricultural Systems* **57**, 271–299. doi:10.1016/S0308-521X(98)00019-5.

State of the Environment (2011) *Australia State of the Environment 2011*. Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Steffen W, Sanderson A, Tyson PD, Jäger J, Matson P, Moore B III, Oldfield F, Richardson K, Schellnhuber H-J, Turner BL, Wasson RJ (2004) *Global Change and the Earth System: A Planet Under Pressure*. IGBP Global Change Series. Springer-Verlag, Berlin.

Steffen W, Crutzen PJ, McNeill JR (2007) The Anthropocene: are humans now overwhelming the great forces of nature? *AMBIO: A Journal of the Human Environment* **36**, 614–621. doi:10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2.

Syvitski J (2012) Anthropocene: an epoch of our making. *Global Change* **78**, 12–15.

Syvitski JPM, Kettner A (2011) Sediment flux and the Anthropocene. *Philosophical Transactions of the Royal Society A* **369**, 957–975. doi:10.1098/rsta.2010.0329.

Tighe M, Reid N, Wilson B, Briggs SV (2009) Invasive native scrub and soil condition in semi-arid south-eastern Australia. *Agriculture, Ecosystems and Environment* **132**, 212–222. doi:10.1016/j.agee.2009.04.001.

Tongway DJ, Hindley NL (2004) *Landscape Function Analysis Manual: Procedures for Monitoring and Assessing Landscapes with Special Reference to Minesites and Rangelands*. Version 3.1. CSIRO Sustainable Ecosystems, Canberra.

Trotter MG, Garraway EB, Lamb DW (Eds) (2009) *Proceedings of the 13th Symposium on Precision Agriculture in Australasia*. University of New England, Armidale.

UN (2012) Millennium Development Goals Report 2012. United Nations, New York.

UNDP (2013) *The Rise of the South: Human Progress in a Diverse World*. Human Development Report 2013. United Nations Development Program, New York.

Vanclay FM (2003) The impacts of deregulation and agricultural restructuring for rural Australia. *Australian Journal of Social Issues* **38**, 81–94.

WCED (World Commission on Environment and Development) (1987) *Our Common Future*. Oxford University Press, Oxford.

Westoby M, Walker B, Noy-Meir I (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **42**, 266–274. doi:10.2307/3899492.

Williams JE, Price RJ (2010) Impacts of red meat production on biodiversity in Australia: a review and comparison with alternative protein production industries. *Animal Production Science* **50**, 723–747. doi:10.1071/AN09132.

Wright T, Wright K, Reid N, Zirkler K (2004) Wool production and biodiversity working together for Tim and Karen Wright, 'Lana'. Land, Water and Wool Case Study. Southern New England Landcare/University of New England, Armidale, NSW.

Yiridoe EK, Bonti-Ankomah S, Martin RC (2005) Comparison of consumer perceptions and preference towards organic versus conventionally produced foods: a review and update of the literature. *Renewable Agriculture and Food Systems* **20**, 193–205. doi:10.1079/RAF2005113.

Young MD (1984) Rangeland administration. In *Management of Australia's Rangelands* (Eds GN Harrington, AD Wilson and MD Young) pp. 157–186. CSIRO Publishing, Melbourne.

Young MD, Gibbs M, Holmes WE, Mills DMD (1984) Socioeconomic influences on pastoral management. In *Management of Australia's Rangelands* (Eds GN Harrington, AD Wilson and MD Young) pp. 79–93. CSIRO Publishing, Melbourne.

20 Beef business management

K. Behrendt, B. Malcolm and T. Jackson

INTRODUCTION

Managing a beef farming business well requires combining land, labour and other resources to make products to sell. This process needs to be consistent with the values, objectives and goals of the business owners in regard to profit, cash and wealth as well as meeting personal and family needs. This is a challenge because farm managers make choices and implement decisions in a natural and economic environment characterised by vagueness, riskiness and uncertainty. This makes farming an exceptionally challenging activity. Extraordinary passion, drive and knowledge are the hallmarks of the operators of successful farm businesses. Done well, though, farming is a rewarding business which meets farm family goals, including the aim of earning returns to capital that are as good as many other investments in the economy.

Managing a farm well requires understanding agriculture, farm economics and human behaviour. Situations, problems and choices that must be managed are made up of a complex interaction of combined phenomena occurring in a risky and uncertain future that can only be predicted by using knowledge from many disciplines. From this, three important consequences flow for managers of farm businesses:

- understandings of, and solutions to, parts of problems are not the same as understandings of and solutions to the whole of problems;
- a whole-farm approach is the best method to analyse, understand and solve the problems and choices involved in managing farm businesses;
- good farm management decisions are based on the best information available at the time. Whether a good decision turns out to be the right decision can be affected by uncontrollable, risky and uncertain future events.

The manager's task is often presented as a sequential, linear process of identifying problems, gathering information about the problem and solutions to it, analysing options, deciding and planning actions, implementing plans, controlling the subsequent performance, responding to changes and learning along the way: it is summarised as planning, execution and control. In practice, the farm management process is non-linear and dynamic because the world managers are dealing with is non-linear and dynamic, with elements of all processes occurring all the time.

Farmers are sometimes caricatured as being motivated to maximise profit from the resources they control. In practice, 'satisficing' is more apt description of farmer behaviour than 'maximising' or 'optimising' (Simon 1955). Goals other than profit always matter. Further, there is a continuum of farmers and farm businesses in regards to intelligence, risk aversion, motivation and skill. Farmers run businesses from the highly commercial and top-performing to subcommercial, poor-performing and purely recreational farming.

Every farmer and farm system is unique, though they confront common natural and economic forces. There are no general best farm systems, only best managers. The interdisciplinary nature of resource management means that common approaches of using disciplinary-based and partial approaches to analysing choices and decisions are inadequate. Farm inputs contribute to farm goals when combined with other inputs, with time and risk playing roles. Only partly explaining what is happening or what might happen cannot solve whole problems. Partial technical productivity analyses (e.g. output per hectare or per tonne of fertiliser) are not substitute methods for the farm economics approach of considering the value, and variability, of all inputs and all outputs in the context of the whole-farm system and the goals of the owners. Whether analysing major strategic farm decisions or tactical and day-to-day farm management decisions, implications for the whole system need to be taken into account.

WHOLE-FARM APPROACH TO FARM MANAGEMENT ANALYSIS

The 'whole-farm approach' to farm management analysis and decision-making means recognising that a farm business comprises many internal and external elements such as human, technical, economic, financial and risk factors; identifying and solving problems; and making sound choices among alternatives, while considering all these key components (Malcolm *et al*. 2005). Unlike solving problems of disciplinary science where the key is to know more about one particular aspect of the problem, identifying and analysing farm management problems and choosing from among alternative actions involves knowing more about the whole problem. The approach recognises that farm management is a human process and it is better to solve the whole of the farm problem roughly than to solve part of the problem precisely. Solutions to parts are not solutions to wholes. The whole-farm approach to analysing farm choices is the farm management economics approach.

The whole-farm approach is based on several key steps, which draw upon an understanding of several key principles. The key steps are:

1. start with the farm stakeholders and their values. This helps set their vision, mission and objectives, which in turn sets the goals the stakeholders wish to fulfil through owning the business. The goals establish why the business is being run the way it is and the desired direction;
2. understand the internal operating environment in terms of available resources (including biophysical, financial and people), the quality of resources and the way and how well resources are being combined. This establishes what could be done, constraints to performance and potential improvements;
3. understand the external operating environment in terms of external influences on decision-making and resource allocation. This establishes areas of risk to the business and opportunities for improving its capacity to meet the farm family's goals.

The key principles underlying the whole-farm approach (farm management economics) are:

- the principle of diminishing marginal returns (for choosing how much of each input to use in production);
- the probability principle (for making decisions in a risky and uncertain environment);
- the principle of increasing financial risk (for choosing how much debt to have);
- the principle of equi-marginal returns (for choosing how much of each farm enterprise to operate).

Principle of diminishing marginal returns

The principle of diminishing marginal returns explains the biological relationships between output and the variable inputs such as fertiliser, seed, chemicals and livestock; these are added to fixed inputs such as land, permanent labour, machinery and infrastructure. For example, the extra (marginal) yield from extra fertiliser might at first be positive, then diminish and even eventually become negative (panel a in Fig. 20.1). Biological responses may differ with the combination of variable and fixed inputs. Farming is very much about combining existing fixed and variable resources and new resources. Different combinations of inputs can be used to make the same amount of output (isoquant; panel b in Fig. 20.1), but the prices of the inputs is needed to identify the combination of inputs that is most profitable.

When changes are made to the combinations of inputs in a farm system, the changes in output are not linear. Instead, they follow the principle of diminishing marginal returns. Thus the key to making decisions is to think, 'If we use a bit more of this input, a bit less of that input, and in doing so create a new combination of all inputs, what change in total output, income and costs is likely to result?' Or, 'If we change the combination of outputs (i.e. produce fewer weaners and more finished stock), how will this affect gross revenue, costs and profit?' As shown in panel c of Fig. 20.1, a given set of inputs can be used to produce many combinations of

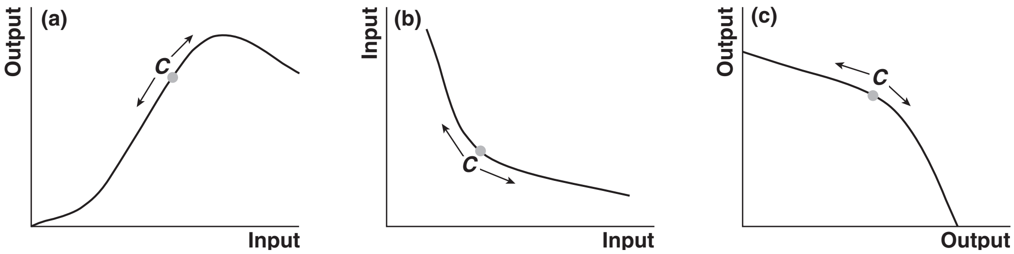


Figure 20.1: Basic relationships that define production. (a) Input–output levels. (b) Input–input substitution to achieve production isoquant. (c) Output–output substitution to achieve a production possibility curve. Source: Adapted from Kay *et al.* (2012).

different outputs (together, these combinations of outputs are called the production possibilities frontier). Like inputs, identifying the best combination of outputs requires considering available prices. The principle of diminishing marginal returns stipulates that information about average levels of output from inputs, as reported by many benchmarking services and imprecisely termed 'technical efficiency', are not a meaningful guide to making decisions about changing the levels of inputs used or outputs produced, because the response is not constant across the range of inputs used and outputs produced. The correct guide to changing farm systems is information about the cost of extra input compared with the extra return that is expected to result. This is called marginal analysis.

Basic production relationships

There are three basic relationships that define production:

1. the relationship between the amount of a resource used and the amount of production (Fig. 20.1a, input–output);
2. the different ways resources can combine and substitute for one another in the production process (Fig. 20.1b, input–input substitution to achieve a production isoquant);
3. the relationship between different products which can be produced with the resources which are available (Fig. 20.1c, output–output activity substitution to achieve a production possibility curve).

Unpredictability and the probability principle

Decision-making is like making bets on the outputs and income that are most likely to result if farm inputs are used in one way instead of another. When evaluating and making farm decisions, the 'how likely' questions can be considered in a structured way by putting some probabilities on the likelihood of different events and outcomes. For example, if it is expected that in four years out of 10 seasons will be favourable, enabling a stocking rate of one beef breeder per hectare without supplementary feed, then there is a probability of 40% of a good season and 60% against it being a good season. When a farmer makes a decision they are unavoidably taking a probabilistic view about the likelihood of success and failure. The whole-farm approach does so explicitly using probabilities.

Principle of increasing financial risk

Invisible aspects of the farm, such as financial arrangements, are important. Financial risk depends on the proportion of debt (borrowed capital) and owner's own capital (equity) that makes up the value of all the assets managed (total capital). The ratio of debt to equity is a critical determinant of whether a business is sufficiently large to earn enough profit to meet the owner's objectives. Debt has an annual cost(interest) which has to be repaid, and that places demands on the amount of cash generated each year.

The principle of increasing financial risk refers to the ratio of debt to equity capital and the way in which this ratio determines the rate at which the equity of an owner of a business grows or declines. Simply, if the annual percentage rate of profit the total capital earns is greater than the annual percentage interest cost of the debt component of total capital, then the size of the owner's capital (equity) grows, and vice versa. The rate at which the owner's capital grows when things go well (the percentage profit is greater than the percentage interest cost) is not as great as the rate at which the owner's own capital reduces when the percentage profit earned is less than the percentage interest rate. The operation of this principle is discussed in more detail below.

Principle of equi-marginal returns

In southern Australia, the majority of farms have a mix of livestock and crop activities. Relationships between activities in a farm system are of a supplementary, complementary or competitive nature (Fig. 20.2). Economic sense dictates that any two activities should be combined in the farm system at least up to the level where they become competitive for resources. Beyond this level, economic analysis is needed to decide which mix of the two activities makes the most profit. The focus of economic analysis thus is on the competitive stage of production.

To decide on the most profitable activity mix, it is first necessary to set out the production possibilities given the available resources (Fig. 20.3). The decision-maker has to answer the question, ‘Given what I have to work with in my farm system, if I grow *x* amount of crop, how much livestock could I produce in my system?’ This question has to be answered for, in theory, all the feasible combinations of the two activities that could be conducted in the system, given the resources available.

The shape of the production possibilities frontier reflects the quantities of each of the two outputs that can be produced in a given year, given the resources available to the farm. This includes consideration of differences in the suitability of different paddocks on the farm for each activity, the amount of capital available for each enterprise, the effects of interactions between the two enterprises and the effects of scale. Once the production possibilities are estimated for a given set of resources (i.e. for a given value of fixed and variable costs), the combination that makes the most profit can be calculated (Fig. 20.3). Instead of farm profit, we can maximise total gross margin (TGM) as, provided the overhead costs are constant for the year, the combination of activities that gives maximum farm TGM would also give maximum farm operating profit.

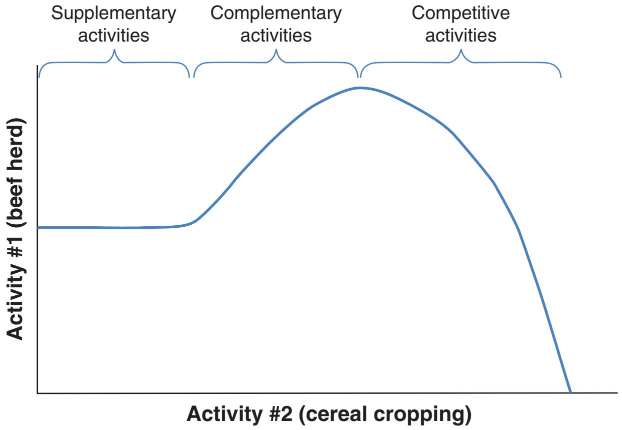


Figure 20.2: Relationships between activities within a farming system.

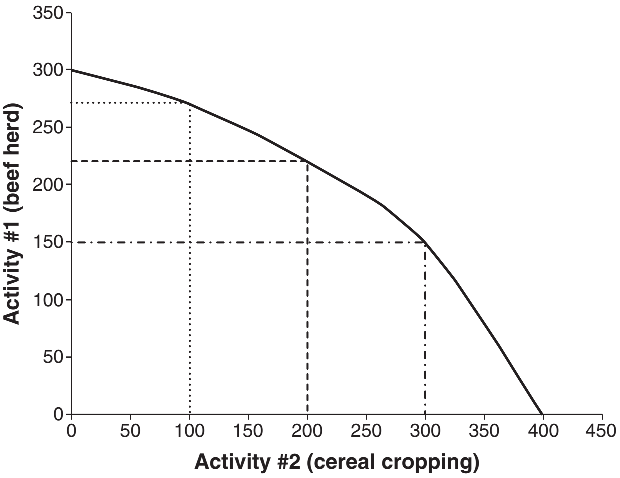


Figure 20.3: Production possibilities curve for two activities within a farming system.

If the expected gross margin (GM) per unit of activity 1 is $275 and expected GM per unit of activity 2 is $180, then for the combination of 150 units of activity 1 and 300 units of activity 2, the TGM is 150 × $275 + 300 × $180 = $95 250. Of the three combinations plotted in Fig. 20.3, the combination which makes the most TGM is 220 units of activity 1 and 200 units of activity 2, which equates to TGM of $96 500. At the other two combinations of output, TGM is lower. When TGM is at a maximum, it is not possible to have a bit more of one and a bit less of the other yet add any more activity GM to TGM. The economic principle is called the principle of equi-marginal returns.

Human component of farm management

The human factor in business management is a critical component (Nuthall 2001, 2010b). Farm assets are managed differently by individuals to achieve different outcomes, even if the potential performance of the starting assets may be identical. Attitudes to risk, external information and management competency are critical components of management and business performance. There are challenges of professional isolation in farming, and managers must adequately develop and maintain a diverse range of skills, from marketing, accountancy and economics to animal, soil and pasture management (Nuthall 2010a). Much external information is not tailored for individual farms, with recommendations made for larger geographic regions or systems. Given the unique biophysical nature of farms and the diverse range of objectives, skills and experience of farmers, such information may be inaccurate or irrelevant for making decisions on particular farms. Information from local sources (the more local the better) is typically more valuable (Lindner *et al.* 1982). Information from external sources can be a source of new ideas to be investigated using more detailed, local information.

In larger corporate-style organisations the issue of multi-disciplinary skills in management can be addressed through employing individuals with different skills and structuring the business operations to form interacting multi-disciplinary teams. In medium-size farming businesses (one to three family members) it becomes increasingly difficult, as the business grows, for the management team to maintain adequate skills and functionality. However, a major advantage of a family size operation is its ability to make prompt decisions under rapidly changing and diverse conditions (Zahra *et al.* 2008).

The characteristics of the labour force are a critical determinant of the performance of a business. This relates to how well those employed by the business engage with the business and its owners. Family labour, or labour closely associated with the values and goals of the business, tends to be more engaged with the business and this motivation leads to improved business efficiency and performance (Maslow 1971). The family structure necessarily introduces issues of succession planning for continuation of both intellectual property and motivation and commitment to the success of the business. A family business without a formal succession plan puts the entire business at risk; succession planning is a critical element of a successful business.

ASSESSING THE PERFORMANCE OF A FARM BUSINESS

The performance of a farm business is ultimately judged on how well it contributes to achieving the goals of the owners. This can be measured by:

- balance sheet at start – a statement of assets and debts before the year's operations;
- efficiency – the profit that is earned from the owner's invested capital and externally borrowed funds (Fig. 20.4), measured as return to capital;
- liquidity – net cash flow representing cash that is available each year to pay all the bills, including paying interest on loans and repaying borrowed capital when it is due (Fig. 20.5);
- wealth – growth, net worth or equity. This is added to the owner's capital after all debts have been repaid;
- balance sheet at end – a statement of assets and debts after the year's operations.

It is important to note that using these measures to assess farm performance requires the use of management accounts and not taxation records, as there are substantial differences between real values and costs of management and those used for tax compliance.

The many goals of owners include the aim of having choices: about standard of living, what to work at, how much and how hard to work, how and where to educate family members, ways to build esteem among peers and the local community, how well and where to retire and so on. The extent and nature of choices is heavily influenced by business wealth generation. This is influenced by the resources available and how well the managers deal with variability. The more efficient, the more net cash flow and wealth is created. Farm business analysis measures efficiency of available resources use, cash earned relative to cash demand, and increases in wealth over time.

Balance sheet

The balance sheet records the total value of the assets and liabilities on a particular day (Table 20.1). Assets are things of value that the manager controls, and the decision on how to use funds for different assets to produce profit and cash flow is a key management decision. Liabilities are debts (claims on the assets of the business). Equity (assets minus liabilities) is the value of the owner's share of the total capital invested in the business.

Claims on assets come from whoever provided the means used to acquire those assets. Equity in a business is the amount the owner can claim from the business, i.e. it is the amount the business owes its owners. Claims on debt are stronger than claims on equity. This means debts have to be paid in full before equity can be returned to the owners.

Assets in the balance sheet can usually be categorised as current, intermediate and fixed. Current assets are expected to be converted to another form of asset or used within a year to produce income or cover expenditure. They include cash, short-term bank deposits, accounts receivable and stocks of inventories such as grain, wool or

Table 20.1: Balance sheet – a statement of assets and liabilities

Assets			**Liabilities (debt)**		
Current assets		**Totals ($)**	**Current liabilities**		**Totals ($)**
Cash	34 000		Trade creditors	5400	
Debtors	2000		Overdraft	1200	
Crop/fodder on-hand	5000		GST owing	22 000	
Tradable livestock – steers, surplus heifers	340 000	381 000			26 600
Intermediate assets			**Intermediate liabilities**		
Breeding livestock (cows, bulls)	460 000		Seasonal crop planting loan	64 000	
Minor plant and equipment	80 000				
Farm management deposits	100 000	640 000			64 000
Fixed assets			**Fixed liabilities**		
Plant and machinery	230 000		Tractor loan	65 000	
Property (1200 ha)	3 600 000	3 830 000	Property loan	800 000	865 000
Total assets		**4 851 000**	**Total liabilities**		**955 600**
			Owner's equity (TA - TL)		**3 895 400**
			Debt + equity		**4 851 000**

trading livestock. Intermediate assets have a life of more than a year and up to seven to 10 years; they include most plant and equipment, breeding livestock and medium-term financial investments. Fixed assets, such as land, improvements and buildings, have a relatively long life. The same categories are applied to liabilities. Current liabilities include bank overdrafts and accounts payable. Intermediate liabilities are loans up to seven to 10 years duration. Fixed liabilities are longer-term debts. In total, debt plus equity is equivalent to total capital.

The value of capital stock varies over the period involved. The average (opening and closing) value of capital invested in production over the period is used as an estimate of the amount of capital in the business over a year.

Profit does not indicate economic efficiency until it is related to the amount of capital used to produce it. Efficiency is the operating profit expressed as the percentage return on total capital (ROTC). ROTC can be compared to the rate of earning on capital employed in other profit-producing activities.

$$ROTC = \frac{Operating\ Profit}{Average\ value\ of\ total\ capital\ (WIWO)} \times 100$$

When leased land or other assets are used, the value is included in the total capital being managed and operating profit is estimated before lease payments are deducted. Operating profit calculated in this way is the return on all the resources used and indicates efficiency of the whole business. When leased land is included in the balance sheet, the present value of future lease obligations are treated as a liability of the business.

Solvency and liquidity of the business are the other relevant aspects of the balance sheet. A business is solvent when assets are more than liabilities. It is insolvent when, if it were to be sold, all debts could not be met. Liquidity refers to the ability to meet all the cash demands in the planning period. A test of liquidity is whether cash and near-cash (current bank deposits, government bonds and securities, saleable stocks of grain, wool, trading livestock etc.) will be able to meet the interest on debts and debt repayments when they fall due in the short- to medium-term future.

It is informative to distinguish between changes in net worth and changes in the asset and debt structure of the balance sheet. These changes have different implications for liquidity. For example, buying assets such as machinery or livestock and paying with cash out of the bank would cause an equal-sized increase and decrease in assets. Accordingly, net worth is unchanged but the structure of short-term assets relative to intermediate-term assets has been affected, and liquidity is changed. Or, taking out a medium- or long-term loan to pay off several short-term loans results in an equal increase and decrease in liabilities, leaving net worth unaffected. The debt has been restructured but the annual debt-servicing requirements, and thus liquidity position, have been changed.

Profit, wealth and cash

Two annual statements (looking backward) or budgets (looking forward) show how a business has performed or is expected to perform over a year. Separately, these two statements detail the profit of the business (and thus how it determines growth in wealth) and its cash flow. These two kinds of statements are discussed below.

Profit and wealth

A statement of profit is based on the returns and costs of the business for a past period. A budget of profit is based on the income and costs expected to occur in a future period. Major changes between the performance in the previous year or two, or changes between the past and the expected profit, can yield valuable lessons. Figure 20.4 depicts how the total opening assets available to the business are used by the manager to produce revenue. The total revenue includes the cash sales of produce plus non-cash changes in the inventory value of livestock and stocks of output such as grain, fodder or wool. After subtracting the variable costs for each enterprise, which typically include the cash costs of growing crops and rearing livestock, a total farm GM is derived. To derive the operating profit, the cost of overheads is subtracted. This includes cash and non-cash costs, such as depreciation and an allowance for the reward/salary of the owner–operator. At this level, operating profit (also referred to as earnings before interest and tax, EBIT) measures the profit generated from the use of total available assets. So, operating profit expressed as a percentage of the average value of total capital is the return on total capital (ROTC) as earlier discussed.

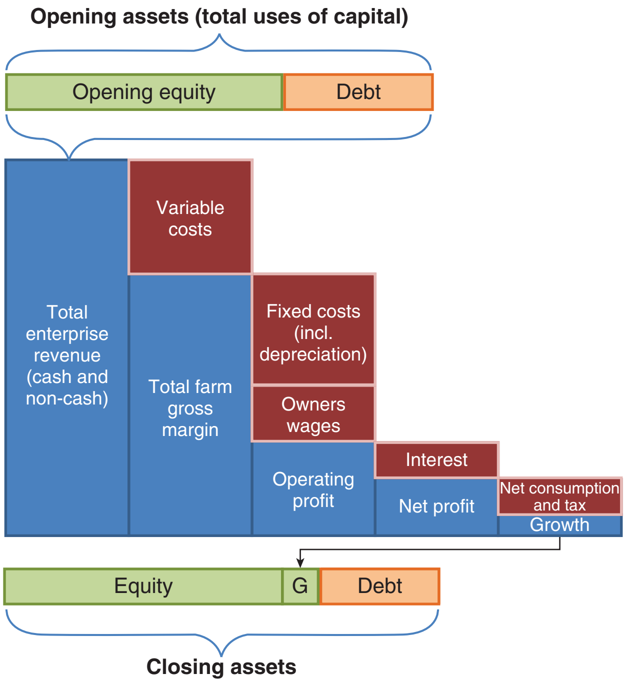


Figure 20.4: Interaction between balance sheets and profitability for the economic analysis of efficiency and growth in wealth. Source: Adapted from Malcolm *et al.* (2009).

After accounting for the cost of credit from external providers of funds (interest), net profit is derived; this is the reward to the farm owners for their invested capital. Net profit expressed as a percentage return to the owners' invested capital is often referred to as return on equity (ROE).

Expenditures for the purchase of capital assets are not considered an annual cash expense but as an investment, since they are typically used for more than one year. The costs of capital assets are allocated within profit statements or budgets over their service life by including annual depreciation as the annual cost. Another important characteristic of estimating the true profit of the business is that the reward for the owner–operator's labour and management is costed at a true market value and deducted to estimate operating profit and ROTC. The value of an owner–operator's labour and management should reflect professional farm managers' salaries, or the salary that could be expected elsewhere (the opportunity cost of labour).

Interest payments on loans are not an operating expense for the calculation of operating profit because they are to do with financing the business, not production, and are a reward to those who supplied capital. Similarly, lease payments are a financing expense and a reward to the owners of the leased assets. Hence, interest and lease costs are not considered operating expenses and are not used to determine the operating profit. Rather, they are used to calculate the net profit returned to the owners for their investment in the business. The net profit can pay taxes, be used for consumption expenditures or new capital investment, or repay debt. Often, an owner–operator's wage is not paid as such, and cash is simply drawn from the business as needed. If the owner does not actually draw out an amount equivalent to their opportunity cost of labour and consume it, then they are 'reinvesting' some of their reward for working in and running the business. This reinvestment may provide resources for repaying debt or undertaking a new investment. The net difference between the operator's allowance and the actual personal consumption (personal drawings),

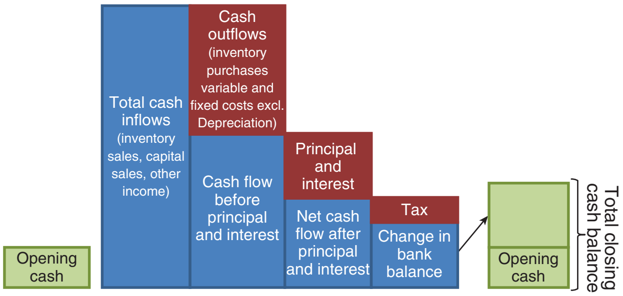


Figure 20.5: The flow of cash through a business for the financial management of liquidity. Source: Adapted from Malcolm *et al.* (2009).

whether positive (consumption less than the opportunity cost of labour) or negative, needs to be added back to the net profit to derive the change in equity (growth in net worth).

In sum, the efficiency of the business is indicated by ROTC. ROTC may be the return on capital owned and borrowed and, where further assets are obtained by leasing, then operating profit is the return on all capital managed (ROTCM). Return on capital indicates how well the resources of the business are being combined.

Cash

Net cash flow is the difference between total cash payments and cash receipts in any given period. A cash flow budget shows cash on hand at the start, where cash came from and went to, and the end balance (Fig. 20.5). A key decision is the balance between the use of short-term credit (e.g. an overdraft or seasonal account) and maintenance of a positive cash balance, especially in highly seasonal production systems where payments and receipts do not align. Cash flow budgets are often used for planning and managing liquidity.

Total cash outflows are subtracted from total cash inflows to derive a net cash flow before debt servicing (Fig. 20.5). To derive the net cash flow after debt servicing, both interest and principal payments are subtracted. This amount net of tax liabilities (including GST, PAYG and income tax) represents the actual change in the bank balance over the budgeted period.

Gearing and equity

Gearing (leverage) ratio is the fraction of equity (assets) funded by debt. It has implications for debt servicing ability and the rate of growth in equity. Conversely, the proportion of assets to debts is commonly expressed as the equity percentage:

$$Equity = \left(\frac{Assets - Liabilities}{Assets}\right) \times 100$$

A high equity percentage means a relatively low gearing. This means less interest and principal to repay and less vulnerability to insolvency if asset values decline.

A balance needs to be struck between having too much of the business returns servicing debt and too little, which limit returns on equity. Gearing has a profound influence on the ROTC and financial risk, as it magnifies the effect of fluctuations in profit on equity. Specifically, when things go well, ROTC exceeds interest costs and equity growth occurs faster than would have occurred with the same percentage returns and no debts or gearing (less total capital is available and being used to generate profits). When things go badly, ROTC does not exceed interest costs and equity is eroded more quickly.

Return on owner's equity (ROE) is related to ROTC, the percentage cost of borrowed capital (INT) and the gearing ratio (D/E) as shown:

$$ROE = ROTC + \left[(ROTC - INT)\frac{D}{E}\right]$$

Thus the effect of differences between ROTC and INT on ROE depends on the debt to equity or gearing ratio.

Businesses with higher ROTC or those that secure cheaper borrowings can operate at higher levels of gearing. Southern beef farmers appear to be adopting higher levels of gearing, which increased from lows of around 2–4% during 1999–2004 up to 8–10% in 2010–11. Northern beef farmers appear to maintain their gearing at around 10–12% from 1999–2011 (ABARES 2012).

Business health: links between profit, cash and growth

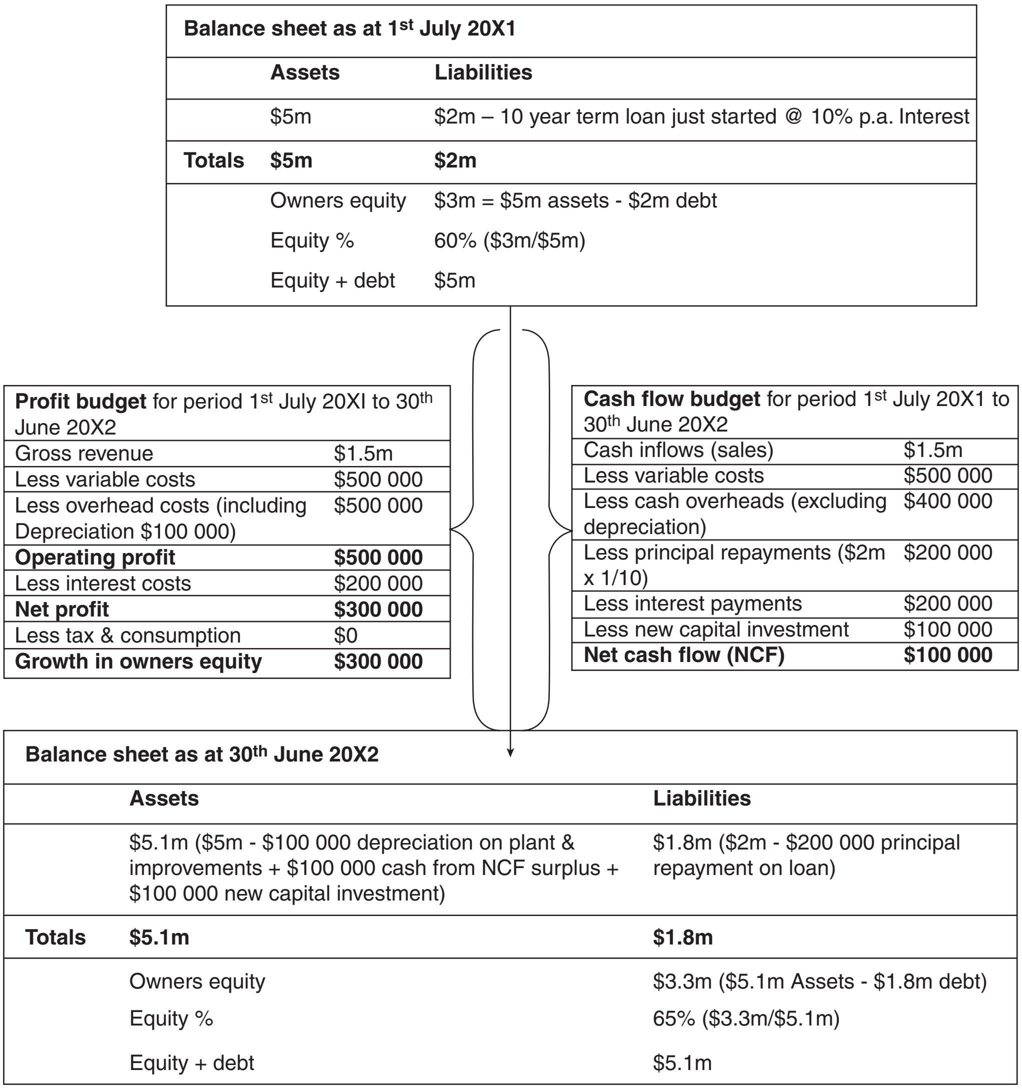
Effective decisions need to be made from broad strategic decisions, such as which breeds of cattle to run, down to narrower technical decisions, such as how much fertiliser to apply to each crop. Financial management decisions influence how a business is structured and how it is financed:

- investment decisions on how business capital is used determine the asset structure (amounts and mix) and the enterprises that comprise the business activities;
- financing decisions on how the business capital is raised determine the liabilities structure (amounts and mix) and the contribution to finance made by the owner;

- profit distribution decisions on how profits are used, including reinvestment and owners' dividends.

  If profit is the means for achieving all owners' goals, then the profitability objective involves maximising profit through planning and control of revenue and expenses relative to the funds employed and the risks taken. Critical factors include rates of return on investment, GMs of different activities, stock turnover rate, and identifying optimal financing methods and asset structures.

The liquidity objective is concerned with solvency, as well as maintaining reputation and credit-worthiness and optimising liquidity through cash planning and controlled management of cash (uses and sources of cash), with the emphasis on optimising not maximising cash on hand in a business. Too much or too little cash will affect profits and ROE but managing this with production, weather, market and other variations is not easy. This is referred to as seasonal variation and it is central to the management of cash flow. Critical factors are maintaining cash balances relative to demands on cash, establishing cash flow projections, determining ability to repay loans (solvency), recovering debts owed and using trade credit. Generally, loan repayments should match expected repayment capacity. A business in financial difficulty should first look at restructuring existing debt commitments to better fit expected annual cash surplus.



Balance sheet as at 1st July 20X1		
	Assets	**Liabilities**
	$5m	$2m – 10 year term loan just started @ 10% p.a. Interest
Totals	**$5m**	**$2m**
	Owners equity	$3m = $5m assets - $2m debt
	Equity %	60% ($3m/$5m)
	Equity + debt	$5m

Profit budget for period 1st July 20XI to 30th June 20X2	
Gross revenue	$1.5m
Less variable costs	$500 000
Less overhead costs (including Depreciation $100 000)	$500 000
Operating profit	**$500 000**
Less interest costs	$200 000
Net profit	**$300 000**
Less tax & consumption	$0
Growth in owners equity	**$300 000**

Cash flow budget for period 1st July 20X1 to 30th June 20X2	
Cash inflows (sales)	$1.5m
Less variable costs	$500 000
Less cash overheads (excluding depreciation)	$400 000
Less principal repayments ($2m x 1/10)	$200 000
Less interest payments	$200 000
Less new capital investment	$100 000
Net cash flow (NCF)	**$100 000**

Balance sheet as at 30th June 20X2		
	Assets	**Liabilities**
	$5.1m ($5m - $100 000 depreciation on plant & improvements + $100 000 cash from NCF surplus + $100 000 new capital investment)	$1.8m ($2m - $200 000 principal repayment on loan)
Totals	**$5.1m**	**$1.8m**
	Owners equity	$3.3m ($5.1m Assets - $1.8m debt)
	Equity %	65% ($3.3m/$5.1m)
	Equity + debt	$5.1m

Figure 20.6: An example of the integrated relationship between profit, cash flow and a business's opening and closing balance sheets. Source: Adapted from Malcolm *et al.* (2009).

Balance sheets and profit and cash budgets are linked (Fig. 20.6). In this example, total assets increased by $100 000 and debt reduced by $200 000. Owners' equity increased by $300 000, from $3 million to $3.3 million, a growth of 10%, which equates to the growth reported in the profit budget. As a result the equity percentage increased from 60% to 65% over the 12 months of operation.

Return and risk

Management is about making decisions that will affect what happens in the future, and implementation, under conditions with risk and uncertainty. So, when assessing the expected performance of a farm business or an activity within it, profit, cash and wealth, and the volatility and risk associated with these measures are all important.

COMPARING BUSINESSES

It is common for technical specialists and advisers to analyse businesses using comparative analysis or benchmarking of average measures of technical efficiency or partial measures of performance (Chapters 10, 18). However, group comparative analysis and benchmarking have many limitations in identifying problems and their solutions (Nuthall 2011). These approaches cannot identify true cause-and-effect relationships and thus cannot prescribe solutions, as all individual businesses comprise a unique mix of resources (Heady 1948). The people operating different businesses have different goals, skills, attitudes, experiences, family situation and stage of life (Nuthall 2010b). The resources available to different farm businesses are different in quantity and quality. The exposure of individual farm businesses to volatility of yields and prices, and lack of control over these key determinants of outcomes, means measures can vary greatly from year to year regardless of how the business is managed (Malcolm 2004; Nuthall 2011). Decisions about input use are made before production occurs and as the seasons unfold the eventual result is measured by physical output and activity gross margins, and so is influenced by factors both within and outside the farmer's control.

Further, maximising average technical ratios of output to input, such as kg meat/ha or cows/ha, is not the means to maximise profit (Candler and Sargent 1962). A high technical efficiency measure, such as average kg meat/ha turned off, will not be the most profitable level of production (Heady 1948; Candler and Sargent 1962). To maximise profit, the aim is to have the marginal cost of producing an extra unit of output just equal to the marginal return from an extra unit of output. The focus of profit analysis is not average physical measures of input (e.g. stocking rate) and output (e.g. kg meat/ha) but expected extra dollar return and extra dollar cost of various levels of inputs and outputs. If benchmarking of technical productivity ratios between different businesses involving different people with different resources, goals, attitudes to risk, stage of life and so on does not provide meaningful information about choosing stocking rate for a system or changing a system, an equally important question is whether it is useful to compare measures of whole-farm economic and financial performance between different businesses.

Summary ratios (often key performance indicators) about whole-farm performance, such as ROTC, can be used to compare performance with other businesses and investments. The comparative ratio of operating profit to total costs (operating ratio) can also be informative. The amount of gross income per capital involved (turnover ratio) informs how effectively the assets are producing profit. Lenders have a particular interest in the gearing ratio as it is one measure of financial risk. The higher the ratio of fixed cash cost to total cash costs, the less flexibility the farm operator has to adjust quickly and efficiently to changing market conditions.

Ratios can also be misinterpreted. For example, two businesses could have the same ROTC but one operator could be too small and not producing enough total cash and profit to continue and grow, while the other operator could be too large and operating inefficiently.

The most useful measures of business performance are measures of efficiency (e.g. operating profit as a percentage of total capital), liquidity (e.g. net cash flow before and after debt servicing, interest rate coverage ratio), growth (e.g. change in equity, gearing ratio) and financial risk (gearing ratio), cost efficiency measured by operating profit over costs, and turnover indicated by gross income over total assets controlled. Trends in such measures over the recent past for a particular business are informative. More useful are the expected movements in these important measures over future planning periods. For financial control, comparing actual and expected business performance, especially cash flows, on a monthly or quarterly basis gives useful information.

Comparisons of average benchmark measures of performance between different farming businesses, and accompanying explanations of cause and effect, are valid only when the available resources (land quality, rainfall, managerial ability, labour quality etc.) are taken into account, the sampling method is adequate and without bias for each farming systems type, correct statistical techniques have been applied and information regarding the statistical accuracy of measurements is provided (Nuthall 2011).

The perennial farmer response when confronted with group benchmarking data comparing how their business is performing relative to some other businesses is commonly: 'So what? Now what do we do?' Farming is about adapting to change and there are no benchmarks for new technologies and new situations. Benchmarking data for individual farms and groups of farms are for a particular time, space and farm system. If collated and analysed using rigorous farm management methods, fully understanding the strengths of whole-farm and marginal economic measures and the limitations of average, partial technical measures, and recognising that the uniqueness of each business means comparing one business over time is the most valuable form of benchmarking, then farm benchmark data can act as a catalyst and starting point for interrogating and analysing performance and the possible merit of potential change in a business (Ronan and Cleary 2000; Nuthall 2011). Regardless, the only way to determine true cause-and-effect relationships and marginal effects and identify changes that will solve business problems is to know the business well, understand where it has been and where it is headed, understand the technology and the technical possibilities (Figs 20.1, 20.3); and use expected prices and costs to analyse the economics, wealth impacts, finance and risk of future strategies for change.

ANALYSING A BEEF ACTIVITY

The economic efficiency of converting feed into saleable cattle and beef products is the key to success of animal enterprise. It depends on the conversion mechanism and method of production, feed sources, costs and returns. The key analytical questions are as follows:

- What is the operating production system?
- What is the target market for turned-off animals?
- How are cattle numbers and beef production maintained (what is the replacement system)?
- How is the health of the herd maintained or increased?
- What are the taxation implications of alternative breeder replacement systems?
- How are the cattle supplied with feed of the necessary quality and quantity, to meet their feed demands throughout the cycle of production and despite seasonal variability of feed supplies (what is the feeding system)?
- How is the overall productive potential of the herd improved over time?
- How do different combinations of activities in the farm system affect one another?
- What is the contribution to whole-farm profit of the various resources used in non-cattle activities?
- What net cash flows result from the beef cattle activities?

Beef activity GM

To estimate whole-farm TGM in the whole-farm profit and wealth budget, the contribution of individual activities (e.g. cow–calf, weaner finishing, steer backgrounding, fodder crops) have to be analysed. This is known as an activity analysis.

The income from an activity minus the non-fixed variable costs is called the activity GM.

The gross income (or revenue) of an activity is the value of the output, whether it has been sold or not. The gross income of livestock activity (Table 20.3) includes the value of offspring produced during the production year, the change in value of animals as they grow a year older and the value of any animal product or by-product sold. Deaths are accounted for as a loss of the capital value of herd (depreciation), and this is deducted in determining trading profit. A livestock trading schedule is used to estimate livestock trading profit (Table 20.2). Livestock trading profit is calculated using the following formula:

$$\text{Trading Profit} = (\textit{Sales} + \textit{Closing value of livestock} - (\textit{Opening value of livestock} + \textit{Purchases})$$

For the whole-farm net cash flow budget, all cash in from sales of animals (and products) and all cash out from costs of animals (purchase of replacements, cash only variable costs) are included.

The flow of animal cohorts through different age groups and classes and its timing is best shown through the construction of a flowchart (Fig. 20.7). In combination with the flowchart, a livestock schedule can provide the base numbers for estimating the variable costs of the activity and their timing.

Flowcharts use rates of birth, culling, death and cast-for-age figures to calculate numbers of each class of animal within each activity. Key parameters include the productive life of cows, calving rate, survival rates and proportion of heifers selected.

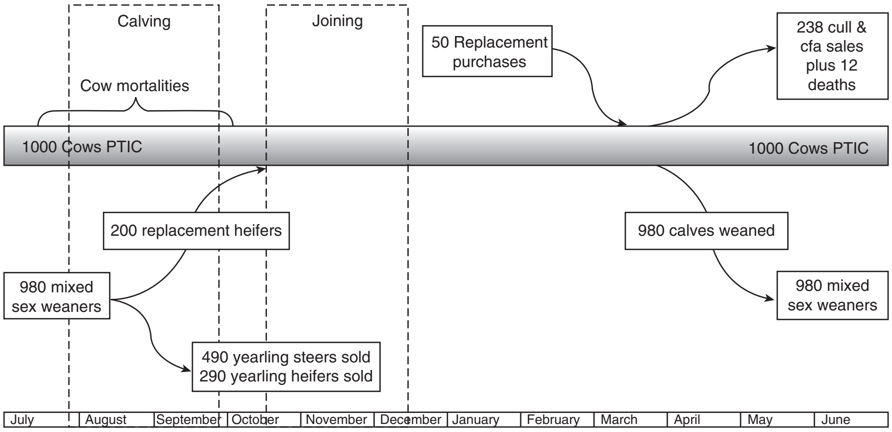


Figure 20.7: Beef production system flowchart for a typical August calving self-replacing herd producing yearling cattle in southern Australia.

It is best to use the same value of similar stock at the start and end of the year, rather than volatile market values.

The main variable costs of a beef activity (Table 20.2) are feed (including maintenance costs of improved pastures, home-grown hay, straw, silage and grains, and any purchased feed and supplements), agistment, contract or casual labour costs, husbandry (including medicines and services such as veterinary) and marketing (including brokers'/agents' fees, yard dues, transport, processing and selling costs). Expenditure on replacement stock is a capital investment and is included in deriving the activity's trading income, even though such costs are often wrongly included in most GM calculations. Similarly, sales of culled cows are included as part of the trading income from an animal activity, even though this is the redemption of a previous capital investment, not income from production. Including purchases of young replacements and sales of old culls captures the difference between purchase price and eventual sale price (the depreciation cost). Depreciation is the relevant annual cost, however, this method of having sales of capital items as income and replacement of capital items as purchases accurately reflects annual depreciation costs of the herd only if the herd is in a steady state. This is rarely the case. The correct way to estimate income from a beef activity is to use a livestock trading schedule in which the annual change in value of each class of animal is recorded (Table 20.2).

MANAGEMENT AND CHANGE

The economic efficiency (Chapter 18) of beef herds is affected by the replacement system (Chapter 14), the feeding system (Chapter 16) and genetic improvement (Chapter 17). Other issues include health challenges (Chapter 13). The penalty costs of failing to take reasonable care of stock health are high. The cost of effective disease control is small in comparison to total farm input costs. Intensive beef production in feedlots (Chapter 11) has the potential risk of disease outbreak if vigilance on animal health lapses.

Replacement system

The method of replacing animals and the costs are important. Herds can be non-breeding, breeding with bought-in female replacements or self-replacing. Non-breeding includes backgrounding store steers or heifers, or finishing purchased vealers and yearlings. Bought-in female replacements include buying-in joined heifers or older joined cows with calves at foot. Self-replacing systems of production involve breeding replacement breeders on the farm. This is more complex and may be based on either purebreds or crossbreeding systems (Chapter 17).

Questions of whether to breed or to buy-in and, if bought-in, at what age cows are bought and at what age they are culled, are central to analysis of a beef production activity (Tozer 2006). For any age class of stock, the decision on whether to cull or to retain for further production depends on the likely price for the cull animal, the expected future production if the animal is not culled and the prices that can be expected for the products, the animal's expected variable costs over the future production period, and tax aspects.

In self-replacing herds, a key question is the most appropriate replacement or cast for age. With ever-changing price ratios and fluctuating seasonal conditions,

Table 20.2: Beef livestock trading schedule

		Sources									Uses										
Asset type		**Opening**			**Purchases**		**Transfers in**		**Natural increase**	**Total sources**	**Deaths**	**Rations**		**Transfers out**		**Sales**		**Closing**			**Total Uses**
	Class	**No. (hd)**	**Value ($/hd)**	**Total value ($)**	**No. (hd)**	**Total cost ($)**	**No. (hd)**	**From**	**No. (hd)**	**No. (hd)**	**No. (hd)**	**No. (hd)**	**Total value ($)**	**No. (hd)**	**To**	**No. (hd)**	**Total receipts ($)**	**No. (hd)**	**Value ($/ hd)**	**Total Value ($)**	**No. (hd)**
Breeding – intermediate	Cows	1000	700	700 000	50	50 000	200	Weaner heifers		1250	12					238	142 800	1000	700	700 000	1250
	Calves	0							980	980				980	Steers, heifers			0			980
	Bulls	25	2000	50 000	5	20 000				30						5	5000	25	2000	50 000	30
Trading – current	Weaner steers	490	450	220 500			490	Calves		980						490	392 000	490	450	220 500	980
	Weaner heifers	490	400	196 000			490	Calves		980				200	Cows	290	203 000	490	400	196 000	980
Totals		2005		**1 166 500**	55	**70 000**	1180		980	**4220**	12	0	0	1180		1023	**742 800**	2005		**1 166 500**	**4220**
Breeding asset values				**750 000**													**Breeding asset values**			**750 000**	
Trading asset values				**416 500**					**Trading profit:**		**$672 800**						**Trading asset values**			**416 500**	

Table 20.3: Typical yearling beef GM (1000 cow herd)

Gross income				**Total (s)**
Trading income				672 800
Livestock products				0
Total gross income *(A)*				672 800
Variable costs				
Eartags	980	calves	@ $3/head	2940
Veterinary and health	2005	head	@ $5/head	10 025
Supplementary feed	1000	cows	@ $20/breeder	20 000
Fertiliser	2000	ha	@ $50/ha	100 000
Pasture maintenance	100	ha	@ $300/ha	15 000
Livestock selling and transport	1023	head	@ $35/head	35 805
Total variable costs *(B)*				183 770
Activity GM *(A-B)*				489 030
GM per breeder				489
GM per DSE[1]				28.78

[1] Dry Sheep Equivalent (DSE) based on annual weighted average DSE rating of 17 DSE for a 500 kg breeder producing an eight-month-old weaner and a proportion of followers.

herd size is rarely in steady-state and its composition can alter after pasture improvement or when there is less culling of young animals. When the size of the breeding herd is being increased, more young replacements are required. The age structure of the herd changes during a build-up phase. In a breeding herd, animal numbers that can be carried through the most limiting feed period are restricted by the number of breeding units. There is interdependence between age classes. A change in replacement policy has ramifications for the feed available for all the activities on the farm, and thus for whole-farm profitability (Buxton and Smith 1996; Turner *et al.* 2013).

For tax purposes, natural increase of stock goes into the livestock trading accounts at concessional notional values decreed by the Commissioner of Taxation, or at some other value chosen by the farmer. Alternatively, trading profit or loss is calculated on the basis of current market value of all numbers and classes of stock. The use of concessional rates for natural increase understates the true animal income in any year, and defers the tax bill until these animals valued concessionally are sold. When sold, they are recorded as cash income and tax is paid on the difference between their book value and sale value. With the alternative approach, using current market valuations for livestock, tax is paid on 'book' gains which may not be realised until animals are sold. In times of low inflation there is little difference in the amount of tax paid, and the option to defer tax can be an attractive benefit. The option is less attractive if later, as a result of inflation and higher prices, a higher tax rate is paid on the livestock income. The self-replacing system contrasts with a bought-in system which has greater cash sales and purchases in any year and thus a higher current tax bill.

The economic concept underlying replacement decisions is that of maximising average profit over time. In theory, it is possible to compare potential income streams from different replacement policies (akin to different crop rotations), and compare the net present value (NPV) or annuities from each 'rotation' of animals under a steady-state system.

Feeding system

Feed available per head affects production per animal, which decreases as heavier stocking rates are reached (Fig. 20.8; Chapter 15). As stocking rate increases, GM per hectare passes the maximum and declines. Maximum GM per head is unlikely to equate to maximum GM per hectare. When hectares of feed are the limiting factor, then output and profit from areas of land are of interest. If land were plentiful and labour was the factor which most limited production, then GM per unit of labour is more critical.

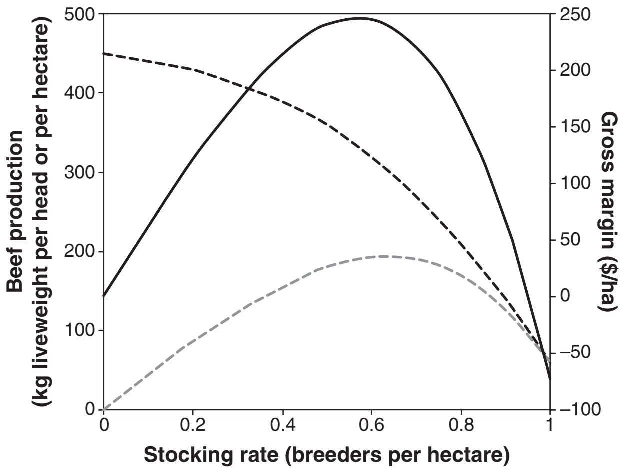


Figure 20.8: Typical relationship between stocking rate and production per head (black dotted line), production per hectare (grey dotted line) and beef activity GM (solid black line). Source: Adapted from Jones and Sandland (1974).

Feed budgeting (matching periods of minimum expected feed demand and minimum expected feed supply; Chapter 15) is based on average expected pasture yields so there needs to be flexibility in cash reserves, high equity (and thus access to credit), fodder reserves or readily saleable livestock such as poor-performing breeders, heifers or steers, to cope satisfactorily with likely climatic variations.

Planning for uncertain seasonal feed supply can include a flexible stocking policy to allow the sale or purchase of a buffer group of dry heifers or steers according to season. Fear of introducing disease and shortage of capital for short-term trading can restrain this strategy, but it is practical. The conventional wisdom of 'sell, prepare to repent, but sell early' indicates that this strategy has been adopted by many farmers with satisfactory results.

The economics of fodder conservation depends on the length and frequency of bad seasons and on the cost of conserving and storing feed (including the cost of depreciating feed value), and feed price rises during poor seasons. Feed deficits can be handled by purchasing supplements, reducing stock numbers (the success of this tactic depends mainly on keeping the animals in good, readily saleable condition) and using the fat reserve of the animals.

Strategies to utilise feed surplus include increasing the condition of existing stock to improve bodyweight (i.e. to increase turnoff weights or for future production), feeding surplus to extra stock (purchased or agisted), conserving feed or carrying it over into the following period, albeit with some loss of quality. Each farm differs and the best strategy needs to be individually assessed. Flexibility is the key to prudent and proactive management of this volatile aspect of beef activity management.

Commercial and home-mixed feed compounds enable a range of high-quality feeds to be directed to the specific nutritional requirements of each stage of livestock growth. In the grazing industry, purchased feedstuffs are used mainly to fill seasonal feed gaps, or the effective stocking rate of the property balances between feed supply and demand through time of breeding, selling policies or trading. It is a characteristic of the more intensively stocked grassland properties that they become progressively more dependent on outside feed.

One source of economic loss on livestock farms is the slow or retarded growth of young animals, especially females, caused by inadequate or unbalanced feed. This leads to a delayed breeding performance and often to lower lifetime productivity (Burns *et al*. 2010).

Analysing changes to farm systems

Adapting the business to short- and medium-term changes is a core task of management. Changes to farm plans can be a change in an aspect of an activity that is fully productive quickly (e.g. fertiliser application to a crop), or change involving significant capital investment that takes time to reach to full potential (e.g. pasture improvement). Key issues in the economic impact of change on farms include market, human and technical factors. First ask, 'What are the market prospects for the output from the change in terms of quantity and quality required, and prices that might be received?'

The farmer and their employees need to have the interests, skills, knowledge and incentives to make a change succeed. The appropriate supply of labour must be available when needed. The life stages of members of the farm family affect what changes are appropriate for any business.

The decision-maker needs to investigate when and how to sell the product(s) resulting from the change, and the likely supply of and demand for the product. The physical aspects to consider are whether there are available resources to carry out the change, or whether extra resources will have to be obtained. Technical needs may include specific types of fertiliser, specific animal husbandry techniques and the methods of growing, harvesting and marketing. A detailed physical plan of the land, machinery, crops and types of animals is required. The technical basis of farm budgets has to be correct.

Experimental results from research plots have to be scaled to be relevant to the specific situation of each farm. Yields used in budgets have to be those that are possible from using economic levels of inputs on the particular farm.

The method for considering the economic prospects of a change involves estimating how much extra profit and extra cash is made from a change in the farm plan, and how volatile these outcomes might be, and comparing the situation without change and with change. This indicates a second question, 'How will farm profit and risk likely differ after a change to the system?' It can be answered by comparing two whole-farm budgets (with and without the change), or constructing a partial budget about only the effects of the change. Impacts have to be assessed in terms of the effects on the whole farm. One approach to evaluating the merit of a change uses a series of questions that need to be answered.

- What is the expected (weighted average) annual operating profit of the farm as it currently operates, without change?
- What is the expected ROTC of the farm as it currently operates?
- What is the expected annual net cash flow of the farm before and after debt servicing as it currently operates?
- What is the expected annual operating profit of the farm, with change?
- What is the expected annual ROTC of the farm, with change?
- What is the expected annual net cash flow of the farm before and after debt servicing, with change?
- Are the extra profit, the extra return on extra capital and the extra net cash flow compared to the extra debt servicing requirement, satisfactory?
- How has the likelihood of achieving outcomes changed, with and without change?
- What other things will change but are not accounted for well in the analysis so far? Do these factors change the conclusion about whether or not to implement the change?

An analysis for a one-year profit budget to evaluate a change can be framed using the partial budgeting technique (Table 20.4). The costs of the change include both additional costs of the change (e.g. variable, overhead and depreciation costs on additional capital invested) and reduced revenue (e.g. forgone sales from reduced production). The benefits of the change include additional revenue (e.g. sales from production in the new activity) and reduced costs (e.g. savings in variable, overhead and depreciation costs if surplus capital is sold). The difference between the benefits and costs represents the net profit from the change to the farming system.

The net change in profit can be expressed as a percentage return on the extra capital invested in changing to the new activity. If the change takes several years to reach full operating capacity (steady-state), then the one year studied should be at steady-state. In this example, the extra capital required for the change is $55 815 ($18 315 of extra cattle (33 hd at 300 kg at $1.85/kg) and $37 500 for Leucenea + grass establishment), which represents a return on extra capital invested of 34% before tax. This allows preliminary comparisons against alternative uses for the extra capital required to make the change. However, a more accurate method to evaluate the ROTC of a change involving several years is the discounted cash flow method (Malcolm *et al.* 2005).

Table 20.4: Using partial budgeting to analyse a marginal change in beef farming systems, replacing 100 ha of tropical grasses with rain-grown Leucenea+grass for a steer trading activity

Costs of the change ($)		**Benefits of the change ($)**	
Additional costs	1333	*Additional revenue*	29750
Beef variable costs ($20/hd @ 1.5 ha/hd)	1250	Beef production (170 kg/ha @ $1.75/kg)	
Leucenea + grass establishment[1]			
Reduced revenue	8750	*Reduced costs*	667
Tropical grass beef production (50 kg/ha @ $1.75/kg)		Beef variable costs from tropical grasses ($20/hd @ 3 ha/hd)	
Total costs of change *(A)*	11 333	Total benefits of change *(B)*	30 417
Net change in profit from making the change, before extra tax = *(B - A)*			**19 084**

[1] Leucenea establishment cost annualised given sowing cost of $375/ha over a 30-year life span.

Source: Data derived from Shelton and Dalzell (2007).

RISK AND AGRICULTURAL PRODUCTION

Risk relates to the volatility of potential outcomes. In practice, farmers take many different steps to place their business in a 'risk situation' which gives a good chance of long-term survival. These include:

- being good at the technology;
- being lowly geared;
- keeping overheads low relative to output, gross income and TGM. This is achieved by keeping production up, judicious expansion, prudent investment in machinery and stock, and high stock:staff ratio specialising or diversifying flexibility in the business structure and the farming system;
- building up non-farm assets, net income and net cash flow from off-farm sources. Invest where there is highest return after tax on marginal capital if there is a reasonable level of farm productivity and investment product knowledge.

Business risk is faced regardless of the amount of debt and equity and level of interest rates. Business risk in agriculture is primarily production and price risk. Financial risk derives from the proportion of other people's money used in the business, relative to the proportion of owner–operator's capital, and the level of interest rates. The higher the ratio of debt to equity, the higher the gearing ratio and the higher is the financial risk which exacerbates business risk.

When making decisions under risky conditions, a good decision is based on the best information and judgement available at the time. Whether a good decision is also the right decision depends on the realisation of risky and frequently unpredictable events. A useful practical approach in assessing risk is to test the sensitivity of results to changes in critical variables, using the 'what if' approach. The decision-maker weighs up all the information in the light of their own judgement about the likelihood of various important events and outcomes happening. Decision risk software can help make more sophisticated decisions based on the probability distributions of outcomes.

Apart from the complementary effects that make livestock an integral component of cropping in many situations, there are sound risk management reasons for diversification (Kimura and Anton 2011). As long as the yields, or prices, are less than perfectly correlated (correlation of +1.0) then having several crops, or even crops affected to some extent by similar growing conditions such as wheat and barley, reduces exposure to income fluctuations. Having both crop and livestock activities reduces the variability of income compared with having only a single crop or a mix of crops. While the effects of diversification on reducing variability are maximum if activity returns are correlated with the degree of –1.0, there are benefits from diversification as long as net returns between activities are less than +1.0. The diversification idea can be extended beyond the farm. One approach is to diversify off-farm and specialise on-farm.

All risk has a cost, and so does reducing risk. Decisions about diversifying activity mixes to reduce the potential costs from income fluctuations also have implications for levels of income. A surer income can be achieved but, beyond a point, it will be lower than a less-certain income. Decision-makers have to weigh up the trade-off between certainty of income and level of income (Anderson *et al.* 1977). The alternative to diversification – specialisation of production – is one of the ways of increasing efficiency of production. There can be a trade-off between doing fewer things at high standards and doing many things less well.

Risk analysis in whole-farm systems

Risk can be incorporated into an analysis by testing sensitivity of the outcomes to volatility of key variables and identifying break-even levels of variables, investigating the combined effects of various levels of key variables occurring at the same time (scenario analysis), using probabilities in tests and/or using probability budgeting methods to estimate the distribution of possible outcomes of changes to farm plans. A spreadsheet add-in program, such as @Risk™, can be used for this.

Formal probability budgeting methods can be used to rank alternative changes to farm plans according to their mean and variance (riskiness) where the decision-maker's estimates of the likelihood of events are used (Hardaker *et al.* 2004). Establishing well-informed estimates of probability distributions is not a simple task, especially once correlated effects between random variables are considered. The decision-maker can then weigh up the riskiness and returns of an option according to their attitude to the risk (passive approach). More formal and complex approaches that include degrees of risk aversion are available but are mainly used in research, given the difficult task of quantifying attitude to risk.

Used well, for major strategic decisions involving considerable risks and volatile potential outcomes, probability budgeting can be a valuable additional source of information for advisers and their clients. However, if used with poor understanding they carry the risk of generating poor-quality information, leading to ill-informed or less well-informed decisions than the very powerful, well-understood, simple budgets that are worked over for sensitivity and a small number of well-thought-out scenarios. Adopting the correct process of budgeting is the key to informed decisions.

Expected value

Instead of using a single value for activity yields and prices, such as a medium-term median, a probability-weighted yield and price can be estimated (i.e. expected value). For example, Table 20.5 shows a range of TGMs which may be associated with a particular activity, and the probabilities of those outcomes occurring. The product of the possible TGMs and their probabilities of occurrence are summed to obtain the 'expected value' TGM of the activity of $644 212, whereas the average or most likely figure is different, namely $615 000.

The expected figure takes into account the range of GMs which are better or worse than average and that could occur, thereby giving a better estimate of the TGM that will be earned over 20 years.

This approach also helps to quantify differences in risk by showing that one activity is more variable but has similar average values. The decision-maker may not view an activity with highly variable GM the same way as another with less variable GMs. The outcomes for each activity, when shown as a distribution, can be considered along with the size of the profit. An activity mix that has lower expected profit over a run of years but is likely to be more reliable and less volatile may appeal to a farmer, given a particular attitude to risk and farm and family situation (debt, stage, goals etc.).

Table 20.5: Expected value of TGM from a range of possible outcomes

Year type	Total GM ($)*(A)*	Probability of occurrence (no. years in 20)*(B)*	Expected value ($)*(C)* = *A* × *B*/20
Worst	215 250	1	21 525
Poor	461 250	6	138 375
Most likely	615 000	7	215 250
Good	707 250	5	176 812
Best	922 500	1	92 250
Total			**$644 212**

A structured way to incorporate risk–return trade-off in a decision is to equate risk–return options to a guaranteed lump sum. For example, if you would accept a certain $60 000 rather than a 50% chance of gaining $100 000 and a 50% chance of gaining $20 000 (0.5 × $100 000 + 0.5 × $20 000 = $60 000), then you are indifferent to the risk of this bet. If you would accept a certain $40 000 in preference to the risky option, you have a degree of risk aversion. If you would need to be paid more than $60 000 to not take your chance, you have a preference for risk. The sum accepted as being equal to the risky investment is called the certainty equivalent sum and it can be estimated for alternative risky investments (or farm activity mixes). For a choice of investments, the choice with the highest certainty equivalent sum is the best choice.

Figure 20.9 shows the distributions of annual operating profit for three possible combinations of crop and cattle in southern Victoria: 1200 ha for livestock, 700 ha for livestock and 500 ha of crops, and 1200 ha of crops. It shows that the

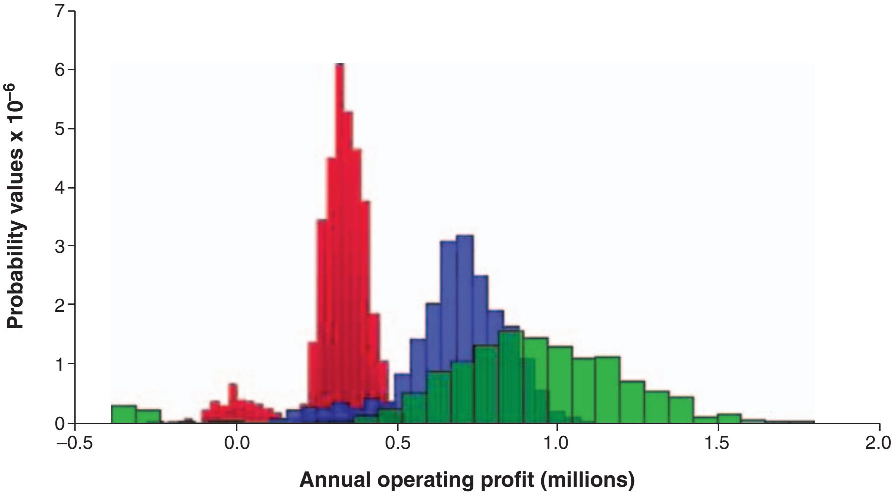


Figure 20.9: Distributions of whole-farm operating profit under three combinations of activities: cattle only (red), mixed farming (7 cattle:5 crop, blue) and crop-only (green).

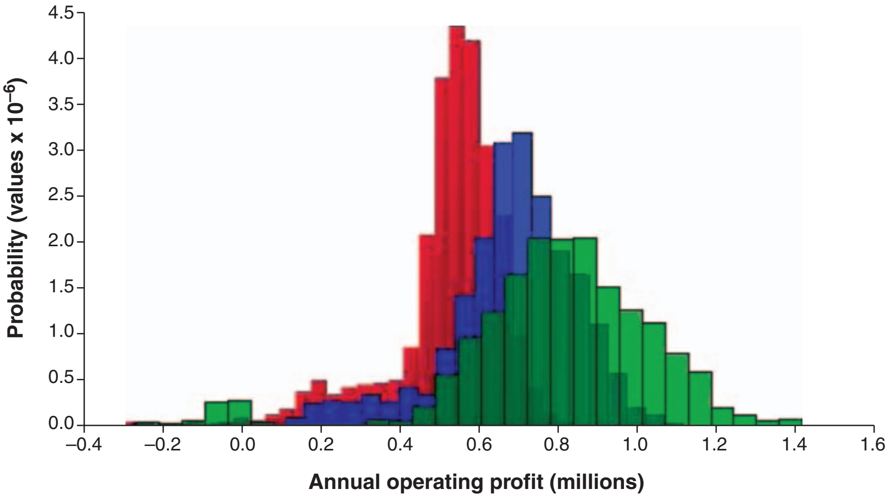


Figure 20.10: Distributions of whole-farm operating profit under three combinations of activities in mixed farming systems: 9.5 cattle: 2.5 crop (red),7 cattle: 5 crop (blue) and 3.5 cattle:8.5 crop (green).

livestock enterprise generates relatively low but stable returns. The cropping enterprise generates higher but more variable returns and is exposed to the possibility of severe crop failure one year in 25 on average. In these years, crops completely fail and the farm makes a significant loss.

The combined farm system generates a probability distribution of farm profit which is less variable than the distribution of profit for cropping only and more profitable on average than the profit from livestock only, reflecting the benefits of diversification. It is still possible for the farm system with combined activities to make a loss, but the probability is lower than for the cropping-only farm system.

Fig. 20.10 shows the distributions of annual profit for three combinations of crop and beef cattle. The combination of 350 ha of beef cattle and 850 ha of crop is similar to the crops-only operation shown in Fig. 20.9, and is the most profitable of the three mixes.

Figure 20.11 shows the certainty equivalent values estimated for a range of attitudes to risk (from highly averse to risk to a low aversion to risk) for the three combinations of crop and livestock. These certainty equivalent values are equal to the average profit of each farm system minus an allowance for aversion to the risk that is associated with the variability of that profit. The value placed on risk depends on risk preferences for Australian farmers (Anderson and Dillon 1992). From left to right, the risk preferences range from 'near-indifference to risk' to 'strong risk-aversion'. Most people fall somewhere between these extremes.

The crop-only system has a steeply declining set of certainty equivalent values because these returns are the most variable of the alternatives, because of the exposure of this system to the relatively large loss caused by crop failure. The cattle-only enterprise has a relatively low and flat certainty equivalent curve, reflecting the relatively low but stable profits earned by this farm system. Combined farm systems are preferred over the largest range of plausible risk preferences. Only at the lowest level of risk aversion is the most profitable crop-only farm system preferred. This is because the inclusion of some livestock means the risk associated with the combined farm systems is lower than that associated with the crop-only system. The combined farm systems are also preferred to the livestock-only farm system at all levels of risk

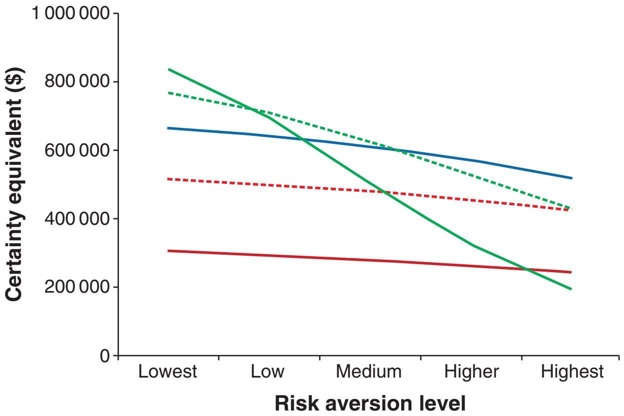


Figure 20.11: Certainty equivalent values of annual operating profit for different combinations of farming systems: cattle-only (red solid), 9.5 cattle:2.5 crop (red dotted), 7 cattle:5 crop (blue solid), 3.5 cattle:8.5 crop (green dotted) and crop-only (green solid).

aversion because they are significantly more profitable. As the level of risk aversion increases, the preferred combined farm system changes from the one with 850 ha of crops and 350 ha of cattle to the one with 500 ha of crops and 700 ha of cattle. This occurs because the livestock enterprise effectively provides a buffer against the occurrence of catastrophic events in the crop enterprise, but at the expense of lower overall profit. Accordingly, farm systems with relatively more livestock will be preferred by people with the greatest aversion to taking risk.

CONCLUSION

Managing a beef business well is challenging and it can be professionally, personally and financially rewarding. Managing a beef business well involves combining the key elements of the business into a whole-system understanding and an operation that has good chances of achieving the goals of management. This is done in the face of much risk and uncertainty. Sound understanding of the whole-farm approach is key, as solutions to problem parts within a system do not solve problems of the whole system. The farm management economics approach is the whole-farm approach. Farm management analysis of choices facing beef businesses is built on a foundation that combines sound disciplinary knowledge and understanding of the human element, the technology, the economics, the finance, the risk and the factors beyond the farm. That is, depth and breadth of knowledge is brought to bear in a structured way to generate information that informs decisions about the performance of the business and the prospects and merits of changes to it. Such whole-of-business mastery is the hallmark of managers of the best beef businesses.

REFERENCES

ABARES (2012) *AGSURF Data*. Department of Agriculture, Fisheries and Forestry/Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. <http://abares.win.hostaway.net.au/ame/agsurf/agsurf.asp>.

Anderson J, Dillon J (1992) *Risk Analysis in Dryland Farming Systems*. FAO, Rome.

Anderson JR, Dillon JL, Hardaker JB (1977) *Agricultural Decision Analysis*. Iowa State University Press, Ames.

Burns BM, Fordyce G, Holroyd RG (2010) A review of factors that impact on the capacity of beef cattle females to conceive, maintain a pregnancy and wean a calf: implications for reproductive efficiency in northern Australia. *Animal Reproduction Science* **122**, 1–22. doi:10.1016/j.anireprosci.2010.04.010.

Buxton R, Smith M (1996) Managing drought in Australia's rangelands: four weddings and a funeral. *Rangeland Journal* **18**, 292–308. doi:10.1071/RJ9960292.

Candler W, Sargent D (1962) Farm standards and the theory of production economics. *Journal of Agricultural Economics* **15**, 282–290. doi:10.1111/j.1477-9552.1962.tb01715.x.

Hardaker JB, Huirne RBM, Anderson JR, Lien G (2004) *Coping with Risk in Agriculture*. 2nd edn. CAB International, Wallingford, UK.

Heady EO (1948) Elementary models in farm production economics research. *Journal of Farm Economics* **30**, 201–225. doi:10.2307/1232526.

Jones RJ, Sandland RL (1974) The relation between animal gain and stocking rate. *Journal of Agricultural Science* **83**, 335–342. doi:10.1017/S0021859600052035.

Kay R, Edwards W, Duffy P (2012) *Farm Management*. 7th edn. McGraw-Hill, New York.

Kimura S, Anton J (2011) Risk management in agriculture in Australia. OECD Publishing No. 39.

Lindner R, Pardey P, Jarrett F (1982) Distance to information source and the time lag to early adoption of trace element fertilisers. *Australian Journal of Agricultural Economics* **26**, 98–113. doi:10.1111/j.1467-8489.1982.tb00618.x.

Malcolm B (2004) Where's the economics? The core discipline of farm management has gone missing! *Australian Journal of Agricultural and Resource Economics* **48**, 395–417. doi:10.1111/j.1467-8489.2004.00262.x.

Malcolm LR, Makeham JP, Wright V (2005) *The Farming Game: Agricultural Management and Marketing*. 2nd edn. Cambridge University Press, New York.

Malcolm B, Malcolm LR, Sale P, Leury B, Barlow S (2009) *Agriculture in Australia*. Oxford University Press, Melbourne.

Maslow AH (1971) *The Farther Reaches of Human Nature*. Penguin, New York.

Nuthall PL (2001) Managerial ability: a review of its basis and potential improvement using psychological concepts. *Agricultural Economics* **24**, 247–262.

Nuthall PL (2010a) *Farm Business Management: The Core Skills*. CAB International, Wallingford, UK.

Nuthall PL (2010b) *Farm Business Management: The Human Factor*. CAB International, Wallingford, UK.

Nuthall PL (2011) *Farm Business Management: Analysis of Farming Systems*. CAB International, Wallingford, UK.

Ronan G, Cleary G (2000) Best practice benchmarking in Australian agriculture: issues and challenges. *Agribusiness Perspectives – Paper 39*,

Shelton M, Dalzell S (2007) Production, economic and environmental benefits of leucaena pastures. *Tropical Grasslands* **41**, 174.

Simon H (1955) A behavioral model of rational choice. *Quarterly Journal of Economics* **69**, 99–118. doi:10.2307/1884852.

Tozer PR (2006) The benefits of management changes in beef enterprises on pastoral stations in Western Australia. In

Proceedings of the 50th Conference, 8–10 February, Sydney. Australian Agricultural and Resource Economics Society.

Turner BL, Rhoades RD, Tedeschi LO, Hanagriff RD, McCuistion KC, Dunn BH (2013) Analyzing ranch profitability from varying cow sales and heifer replacement rates for beef cow-calf production using system dynamics. *Agricultural Systems* **114**, 6–14. doi:10.1016/j.agsy.2012.07.009.

Zahra SA, Hayton JC, Neubaum DO, Dibrell C, Craig J (2008) Culture of family commitment and strategic flexibility: the moderating effect of stewardship. *Entrepreneurship Theory and Practice* **32**, 1035–1054. doi:10.1111/j.1540-6520.2008.00271.x.

This page intentionally left blank

21 Australian beef cattle: case studies

P.E. Schuster and C.E. Bagshaw

INTRODUCTION

Australian beef production enterprises extend throughout a vast continent of 769 million ha and a range of different production environments (Chapters 9, 10). The case studies in this chapter show how various challenges are managed in different environments. The location of case study properties is provided against the backdrop of mean annual rainfall (Fig. 21.1) and rainfall variability (Fig. 21.2). The studies are not presented as cases of best practice.

CASE STUDY 1: MATCHING FEED DEMAND AND SUPPLY

Background

Craig and Donelle Forsyth, with their children Brooke and Nathan, run a cattle finishing operation near Irwin, Western Australia, where they match feed supply with feed demand from the cattle and minimise supplementary feeding.

The Forsyths finish cattle for five northern pastoral clients from the Upper Gascoyne and the Kimberley

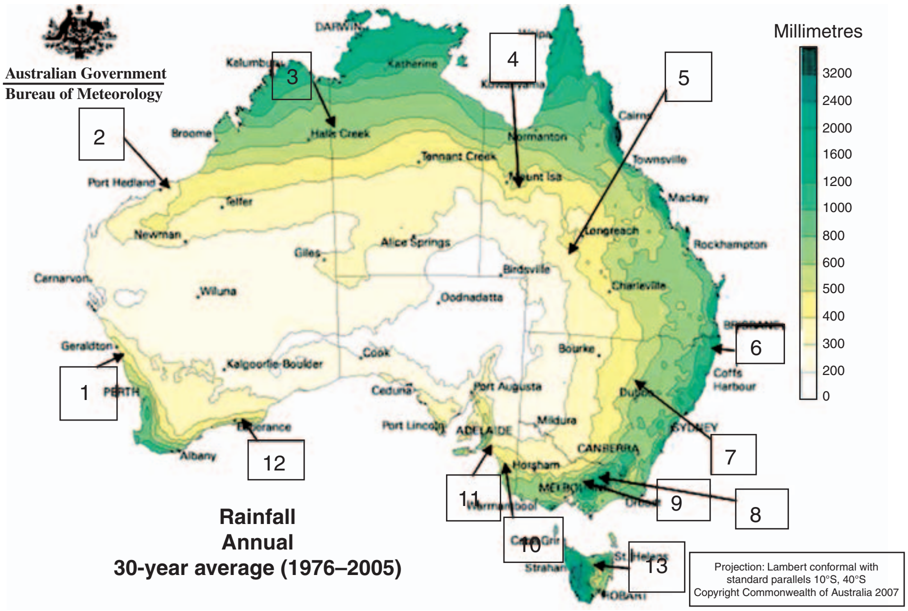


Figure 21.1: Location of case study properties in relation to average annual rainfall. Source: BOM (2012).

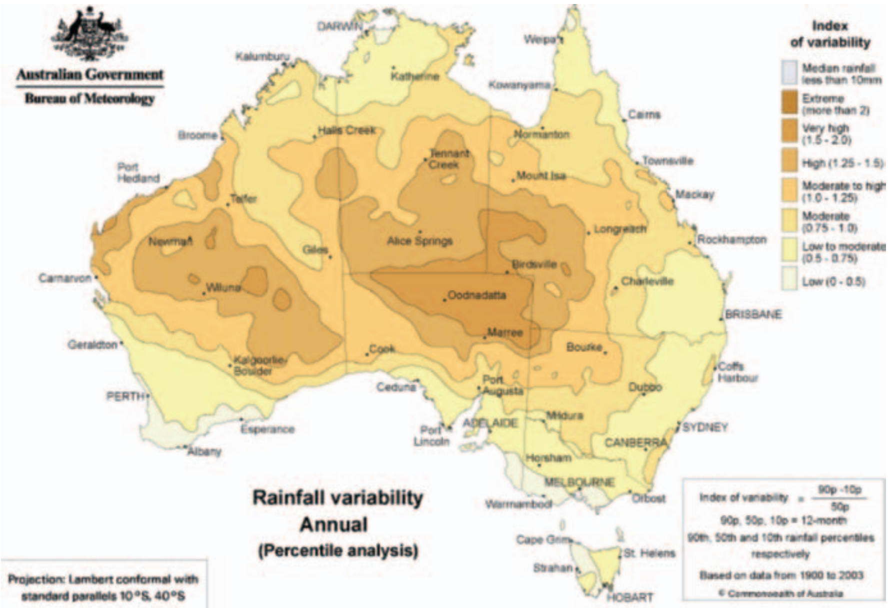


Figure 21.2: Rainfall variability (percentile analysis). Source: BOM (2012).

regions of Western Australia. The composition of their diverse pasture, based on perennials, allows them to optimise pasture growth and utilisation while maintaining the flexibility to adapt to variable seasonal conditions.

A mob of their own breeders is incorporated in the operation but their primary enterprise involves controlling the weight gain of the northern cattle under their management.

At a glance

- Producer: Craig and Donelle Forsyth.
- Property: Avoca.
- Location: Irwin, Western Australia, 400 km north of Perth.
- Area: 3600 ha, 3000 ha of which is arable.
- Annual rain: 425–450 mm.
- Soil: sand and sand over gravel.
- Pastures: Rhodes grass, Gatton panic, serradella, annual clovers and tagasaste.
- Enterprise: cattle finishing for northern pastoralists – ~3000 head per year.
- Target markets: finishes 50% for live export and 50% for domestic markets.

Then and now

The Forsyths used to run only their own cattle; however, a series of bad seasons in the late 1990s and early 2000s forced them to sell most of their stock and re-evaluate their business. They trialled oversowing some annual pasture species with perennials and were thrilled with the results (Fig. 21.3).

This new productive potential, together with a desire to minimise the risk involved with the cattle operation, encouraged the Forsyths to follow the suggestion of a local agricultural department employee and background cattle for northern pastoralists. They approached several pastoralists, based on recommendations and pre-existing relationships – transparency, trust and mutual respect are critical to success in this kind of arrangement.

Craig is relishing their new low-risk cattle operation. They no longer need to spend time or money searching for the right cattle for the property and they are now able to plan feed availability well ahead for the five reliable pastoral suppliers.

Feed supply

The number of cattle the Forsyths can background on Avoca is dependent on the amount of available pasture (Fig. 21.4). It is not economical to supplementary feed more cattle than the available feed can sustain, and the Forsyths use pasture budgeting to ensure that the feed on offer meets the requirements of the livestock on hand. The feed demand calculator, stocking rate calculator and rainfall to pasture growth outlook tools available from Meat and Livestock Australia (MLA 2012a, b, c) can help determine the appropriate number of livestock for a particular grazing situation. Livestock are sold or bought to manage this balance.

Figure 21.3: Oversowing annual pastures with perennials has significantly lifted production.

The carrying capacity and productivity of Avoca have been significantly improved in recent years through a dedicated pasture improvement program. Avoca had a good covering of serradella and annual clover, to which perennial and subtropical pasture species, including tagasaste, have been added. These have not only filled the summer feed gap, but have improved the performance of the annuals. Where the Forsyths could once rely on a beef production of 50 kg liveweight gain per ha per annum, they now average 220–280 kg on the perennial pastures and 120–150 kg on the annuals.

They believe that an annual pasture fertilisation program is essential in enabling them to have the necessary feed for peak periods of demand. Craig generally uses 50–60 kg/ha of superphosphate plus Flexi N liquid fertiliser as required on the perennial pastures; it has not been used in recent years as the legumes have supplied sufficient nitrogen through fixation.

Figure 21.4: Stocking rate is matched to feed availability.

Matching feed supply to demand

The introduction of perennial and subtropical pasture species to Avoca, including Rhodes grass and Gatton panic which were oversown on annual species, broadened the seasonal availability of pasture. As a result, the Forsyths were able to ensure that pasture was well established in spring and that it would continue to grow throughout summer and into early autumn, times when feed supply was traditionally poor (Chapter 15). The bulk of cattle are organised to arrive from April and throughout winter once this feed is well grown.

Depending on the season, the Forsyths receive up to 3000 head of cattle, often retaining 600–1000 of them for the duration of the summer months. Cattle are received at weights of 100–300 kg with most between 180–260 kg. Many of the cattle from the Upper Gascoyne are destined for live export so they must carefully manage weight gain and ensure the cattle stay below, but as close as possible, to the 350 kg limit. Kimberley cattle generally arrive at ~200 kg liveweight and the Forsyths aim to grow these to 330 kg for the domestic market (Fig. 21.5).

The Forsyths begin organising the sale of the cattle on Avoca by the end of August, having a good feel for their weight gain capacity by that time. They sell some of their own herd with the clients' cattle, which offers the clients peace of mind that the best price possible is being attained as the producers have a financial stake in the transaction via their own cattle.

Where possible, cattle are sold between September and December, the smaller animals being retained throughout summer and into autumn in order to reach required weights. Most cattle will stay on Avoca for approximately six months. This turnaround enables the Forsyths to match available feed supply with the demand from the cattle, before allowing pastures to re-establish before the next year's intake. The MLA feed demand calculator

Figure 21.5: The finished product.

(MLA 2012b) has been useful in matching feed demand to supply.

At no time do the Forsyths take ownership of the northern pastoralists' cattle. Rather, they own the weight the cattle gain on Avoca and take all care and responsibility for the cattle while on their property. Cattle are weighed on arrival and regularly throughout their time on Avoca to ensure they continue to grow towards the required weight for their designated markets. When the cattle are sold, the Forsyths are paid the c/kg market price for the kilograms added while the cattle were in the Forsyths' care, i.e. the sale weight, less the arrival rate, multiplied by the c/kg sale price. The northern pastoralists benefit through the security of having an assured market through the Forsyths, access to southern markets and not having to deal with marketing and sale logistics.

Producer support

The Forsyths find local producer groups an invaluable support and education tool in their cattle operation. Craig regularly participates in education days and pasture trials and finds that such resources help keep him up-to-date and enable him to benchmark their property (Chapter 20).

Key messages

- A flexible and open business mindset is needed to recognise opportunities in any industry.
- Animal numbers can be managed to maximise pasture production and profitability by matching feed supply and demand.
- Producer groups can offer agricultural producers valuable benchmarking opportunities.

CASE STUDY 2: WEANER EDUCATION FOR LIFELONG BENEFIT

Background

Annabelle Coppin manages vast Yarrie Station, encompassing 400 000 ha in the east Pilbara of Western Australia. The scale of the property means it is feasible to muster and wean only once a year, and this generally takes four months from May to September (Fig. 21.6).

Annabelle implements a yard-weaning program which she finds quietens the cattle, making them less stressed and easier and safer to handle for the rest of their lives. While there are costs associated with yard-weaning such a large number of cattle in an isolated location, Annabelle believes the benefits outweigh such costs.

Figure 21.6: Mustering on Yarrie Station.

At a glance

- Producer: Annabelle Coppin.
- Property: Yarrie Station, East Pilbara Cattle Co.
- Location: East Pilbara, Western Australia.
- Area: 400 000 ha.
- Annual rain: 300 mm.
- Pasture: spinifex and buffel grass.
- Enterprise: 3500 breeders, predominantly Shorthorn, Brahman and Droughtmaster cross.

Weaning opportunities

Not only is weaning a necessary aspect of any cattle breeding operation (Chapter 14), ultimately benefiting the cow and allowing her to regain body condition for producing another calf the following year, Annabelle views it as an opportunity to instil lifelong lessons in the calves.

Yard-weaning allows the weaners to become used to handling, the noise and movement of other cattle, humans, vehicles and dogs. It enables them to establish social orders in confined spaces and gets them used to eating new foods, such as hay or supplements. The close confines expose weaners to common health conditions in the herd and can improve their immunity (Chapter 13).

Weaning is one of the main animal husbandry processes on Yarrie Station, with weaners trucked from various bush yards to the central yards for handling and marking over a period of around four months.

Be prepared

Annabelle stresses the importance of being prepared. Yards must be checked and functioning well. Good feed, water and the necessary labour must be available and a plan prepared so any last-minute rush is avoided. The Coppins truck hay to Yarrie from their southern property near Badgingarra, 150 km north of Perth, which is used during the weaning process. Good preparation and planning helps minimise stress to weaners, the single largest health concern in yard-weaning.

The process

Once yarded, weaners are drafted into lines depending on their ultimate destination. This also ensures that animals of a similar size are worked together. Very small animals will ultimately be trucked to the Coppins' property near Badgingarra, where they will have access to better pasture. Some bull weaners will be sold immediately for live export to the Middle East. Others are castrated and kept as steers. Some heifers are retained as replacement stock and joined for calving the following year while the culls are sent to the southern property for further backgrounding.

In the yards, weaners are worked in small mobs of up to 50 to avoid bullying and to allow all animals to be exposed to handling activities. Set activities are conducted as follows.

1. Introducing weaners to pressure – holding and moving. Weaners are positioned in a line and made aware of the presence of the handler. The mob should be taken to one end of the yards and held without being pressured excessively. When settled, they should be taken with a person in the lead to another corner and allowed to settle. The weaners should be still and calm in the corners and respond to pressure from the handler.
2. Establishing mob structure.
   This activity is aimed at training weaners to stay in a mob and follow leaders, both people and cattle. A handler is placed in the lead with another on the tail and the cattle are moved between the yards within the main yard compound. Cattle that will take the lead are identified and encouraged to do so, and the mob should not be allowed to string out excessively. The tailing handler keeps the mob connected with the lead and helps pressure through the gates.

   This needs to be continued until the mob is connected to the leader, moving easily around corners and through gates. When the flow is consistent, the mob should be parked on the water trough. This activity must be repeated and pressure ultimately released once the mob is responding to requirements.
3. Moving through gates and into small spaces.
   The aim of this is to teach the weaners to look for gates and control speed. Once cattle have settled from the above activity they should be moved in and out of two yards within the main yard complex, ideally in parallel. A handler on the side must apply pressure to encourage weaners through the gates, and another do the same on the tail. Cattle should move smoothly, without resistance, and stand still with the gate open.

   Once settled, the cattle are moved back with one handler in the lead and one on the side slowing or speeding them. Again, this process is repeated until cattle need minimal pressure to move quietly between pens, are looking for gates to move through and are responding to parallel pressure, whether slowing or speeding.
4. Introducing the race.
   Once weaners are completing the above activities with minimal stress, they can be confidently put through the race. This can generally be done by one handler who needs to open the race and pressure the weaners, letting them flow with as little force as possible.

If the cattle are still stressed, fast or flighty at the end of these activities, the entire process needs to be repeated and slowed down.

The whole process may take anywhere from two days to a week. After this time, the weaners are tailed out from the yards with at least two handlers using horses at the lead to control the speed of the mob. The cattle should walk out calmly and look to feed. Cattle can be re-yarded for the next couple of nights in order to strengthen their familiarity with the yards and to ensure they find water and are protected.

Costs of yard-weaning

Yard-weaning has been common and routine practice in northern production systems for many years, and similar practices are now being applied in southern systems. Annabelle admits there are significant costs involved, but believes the benefits outweigh them. She identifies the two main costs as labour and feed.

Yard-weaning at Yarrie requires at least two full labour units consistently working the weaners in the yards over the course of the four-month weaning period. The cost of the hay, which is transported 1400 km from their southern property, is also significant.

Despite these costs, Annabelle believes the benefit far outweighs the expense. Cattle that have been through the yard-weaning exercise are easier to handle for the rest of their lives and become less stressed when handled. This contributes to a safer workplace and to higher potential weight gain.

Key messages

- Yard-weaning should be planned well in advance so it can be implemented quickly and easily with minimum stress to handlers and cattle.
- To be most effective, cattle should be trained in small mobs (up to 50) of similar sized animals.
- Yard-weaning can greatly influence the temperament of cattle for the rest of their lives, resulting in calmer, less stressed animals.

CASE STUDY 3: MANAGING SUPPLEMENTS IN A TROPICAL PRODUCTION SYSTEM

Background

Patrick Underwood and his family own and run the vast tracts of Victoria River country that are Riveren and Inverway in the north-west of the Northern Territory.

Recent years have been challenging for the Underwoods, as they have been for most Northern Territory producers, with the main market for their cattle, the live export trade, being increasingly scrutinised and unreliable (Chapter 12). This has coincided with significant increases in major input costs such as supplements, requiring producers to rethink their management plans.

Patrick now closely monitors all costs in the business and considers these against their potential benefit. This includes expenditure on supplements, which still amounts to around \$250 000 annually, even when provided on a strict cattle class priority basis.

At a glance

- Producer: Patrick Underwood and family.
- Properties: Riveren and Inverway.
- Location: headwaters of the Victoria River area in the Northern Territory, 600 km south-west of Katherine, 70 km from Western Australia border.
- Area: Total 520 000 km^2 (Riveren 301 800 ha; Inverway 253 800 ha).
- Enterprise: 40 000 cattle (Riveren 23 000; Inverway 17 000), of which 17 000 are breeders and 3000 joiners (heifers to be joined or mated). Primarily production of Brahman cattle for live export trade, with some Charbray.
- Soil type: classic Victoria River country, black soil basalt with some harder red country.
- Pastures: Mitchell, Flinders and bluegrass on better country with spinifex and several more palatable grasses on the red soil.
- Water: artesian bores, sunk to an average depth of 30–50 m (up to 100 m), supply raised ‘ turkey’s nest’ dams which then gravity-feed to troughs in surrounding paddocks.

A changing market

The Underwoods have seen the marketing landscape of the Northern Territory cattle industry change considerably over the past five years. Relatively stable live export markets, particularly Indonesia, have contracted and now dictate tighter supply specifications while what were once relatively constant input costs have become volatile, following a sharply rising trend. This has required northern cattle operations, particularly those that are still family-run, to redefine their management strategies to remain viable.

Australian cattle entering the Indonesian market are subject to various import restrictions which must be well understood by producers wishing to supply this market. One such restriction, which has a significant effect on the Underwoods’ operation, dictates a maximum liveweight of 350 kg. Due to this restriction, the Underwoods are able to supply to the trade only young steers and the 40–50% of heifers that are not retained for breeding. Alternative markets have to be identified for cull bulls and cows.

Patrick explains that while some live export markets have opened for these cattle, including Brunei, the Philippines and Malaysia, the remainder are transported to eastern markets, primarily Midfield Meats at Warrnambool in Victoria and Bindaree Beef at Inverell, New South Wales, incurring a \$200/head freight cost. As a result, the business’ profitability has been significantly affected and modified management strategies have had to be adopted, such as retaining breeders for longer.

The perennial question: cost versus benefit

Given the vagaries of the live export market and consequent strain on financial resources, what the family would like to supplement their cattle and what they actually do are significantly different. The final decision is made seasonally following a cost–benefit analysis (Chapter 20).

Ultimately, supplements are provided to increase the overall calving and weaning percentages of the herd. While many operations refer to calving percentage to benchmark production, Patrick maintains that weaning percentage provides a more realistic picture of productivity. The Riveren/Inverway stations average 65% weaning (65 calves weaned per 100 cows joined) and achieve 70% in good years. While Patrick accepts that Brahman cattle are not the most fertile of the cattle breeds (Chapter 9), he is adamant that their resilience to tropical conditions more than compensates for this.

Figure 21.7: Steer weaners.

Another important driver of productivity in northern breeding programs is growth rate in young cattle. Not only does a high growth rate result in steers reaching target market weights sooner (close to but <350 kg) but heifers become fertile sooner, as fertility is largely determined by liveweight and condition score. The Underwoods would ideally like to heavily supplement all young cattle (Fig. 21.7) to reach desired weights earlier, whether to meet live export weight specifications or desired mating weights in heifers; however, the cost of supplements requires a more targeted approach.

Types of supplements

The key ingredient of most supplements in tropical Australia is urea, fed in combination with sulphur in the dry season and phosphorus in the wet (Chapter 16).

Urea in combination with sulphur at a ratio of ~13:1 aids the digestion of dry, low-quality grasses by feeding rumen microflora. This not only enhances the microflora's ability to digest grass but also increases the number of microflora available to be washed out of the rumen and into the small intestine, where they are digested and absorbed as a valuable source of protein for the animal.

Over the wet season, the urea-based supplement is replaced with phosphorus which is deficient in the long, sappy, green feed. Phosphorus deficiency in cattle can lead to decreased weaning percentages and bone deformities (Chapter 13).

SUPPLEMENTING DIFFERENT CATTLE CLASSES

Weaners

Cows and heifers are joined to calve from October to December in the lead-up to the wet season. This means that the cow will carry her calf through the wet season when green feed of better nutritional value is on offer (Fig. 21.8).

First-round weaning takes place during May and June when up to 80% of the weaners to come in that year are weaned, with the majority averaging 120–160 kg. At this time, most of the residual feed from the wet season has hayed-off and is of declining feed value, meaning that

Figure 21.8: Cows and calves ready to come in for weaning.

supplements are required for the weaners to continue to develop and meet target weights. This is when the Underwoods use the starter ration, which is a loose mix with a high content of grain to improve palatability and some urea. Providing this ration as a loose mix encourages the weaners to consume more than they would if it were in the form of a lick block.

The remaining 20% of calves are weaned at the second weaning. These are generally lighter than those weaned earlier, as their lactating mothers have been on poorer-quality feed.

The total annual cost of starter rations fed out to weaners by the Underwoods is about $10/head/year although this varies depending on the season and the type of country (more supplements are used on poorer country).

Another benefit of feeding out the starter ration to weaners is the quietening effect. By familiarising cattle to noises, vehicles, people and other animals as weaners, they become easier to handle for the rest of their lives.

Joiner heifers

Heifers to be joined (mated) receive a sufficient amount of lick, either urea-based in the dry season or phosphorus-based in the wet season, to ensure they gain condition as quickly as possible and meet the crucial joining weight at the earliest possible time. Based on experience, the Underwoods believe that providing licks to this class of cattle improves conception rates by ~20% (Fig. 21.9).

Out-of-season calvers

The final class of cattle to receive licks are the needy portion of those cows that calve out of season; the mothers of the second-round weaners. If cattle are in poor condition leading into a wet season, generally the late calvers, some will be lost as the environment becomes challenging. Weak cattle bog easily with the high clay content in the black, basalt-rich soils that become muddy. Even if these cows survive, they are unlikely to conceive due to their poor condition.


Figure 21.9: Joiner heifers.

As a result, it is not uncommon for cows to calve twice every three years and this is one of the major issues affecting productivity in northern Australian cattle herds (Chapter s 9 and 14). Understanding this issue, the Underwoods isolate and supplement late-calving cows with licks to help them regain condition before the upcoming wet.

Then and now

Five years ago, practically all Riveren and Inverway cattle were provided with licks. The benefit was not, however, equally shared: the larger, stronger cattle monopolised the supplements and little found its way to those that needed it most.

The more targeted approach, in which cattle were better segregated based on their needs, led to more targeted supplementation and therefore improved benefit:cost through:

- reduced costs (despite increasing input costs);
- reduced mortality rates;
- increased weaning percentages.

Key messages

- By identifying the most needy classes of cattle and supplementing accordingly, operating costs can be greatly reduced.
- Cattle must be in good condition leading into a wet season; supplements can help achieve this.
- Supplements, particularly urea in the dry and phosphorus in the wet, are necessary for maximising productivity and profitability in northern Australia.

CASE STUDY 4: MINIMISING EXTERNAL PARASITE IMPACT TO MAXIMISE PRODUCTION

Background

Rodger Jefferis, his wife Lorena and children Grant and Brooke run a white Brahman cattle stud, Elrose, near Cloncurry and a commercial Brahman herd on properties across Queensland's northern and central regions.

While acknowledging that external parasites, particularly cattle ticks and buffalo fly, are a significant management concern in central and northern Queensland, the Jefferis family believes that, with focused breeding and genetic selection, graziers can minimise their impact.

At a glance

- Producer: The Jefferis family.
- Property: Elrose.
- Location: Cloncurry, north-western Queensland.
- Area: 32 400 ha.
- Annual rain: 380 mm.
- Enterprise: Grey Brahman stud (2000 performance-recorded breeders) and 20 000 commercial Brahman breeders.
- Country type: country varies from red spinifex hills to black soil downs.
- Pastures: buffel grass and spinifex.
- Target market: all commercial cattle are accredited for sale to the European Union.

The benefits of breed

The Jefferis family is well aware of the management concerns associated with external parasites in northern Australian cattle operations, namely cattle ticks (*Rhipicephalus (Boophilus) microplus*) and buffalo fly (*Haematobia irritans exigua*), and is committed to the role breeding can play in minimising these (Chapters 9, 13, 17). Rodger is a keen advocate of Brahman cattle and while some suggest the Brahman influence in the north could be diluted (Chapter 9), he explains that they have a genetic resistance to the cattle tick and are less susceptible to buffalo fly given they have less hair than other breeds, particularly *Bos taurus* cattle.

All the dips used to treat cattle tick on Elrose station were decommissioned long ago, despite the property being above the 'tick line' (an imaginary tick barrier which runs east of the Great Dividing Range and north of the Great Northern Rail line at a latitude of ~19.25°S; Chapter 3).

The Jefferis family attributes the lack of ticks to their pure Brahman cattle herd (Fig. 21.10). They explain that graziers in northern Australia who introduce non-resistant breeds of cattle must be constantly vigilant and manage for cattle ticks which, if left untreated, can cause loss of condition and even death due to 'tick worry' and blood loss. Ticks can transmit tick fever organisms, which can cause illness and death.

Northern graziers without tick-resistant cattle primarily control ticks through strategic treatment with chemicals, the cattle tick vaccine and rotation of pastures. All these methods require a significant investment in labour and/or chemicals, which has resulted in a reduced focus on tick control and an associated decrease in productivity in recent years as costs have increased.


Figure 21.10: Grey Brahman.

Rodger maintains that Brahman not only minimise the need to manage ticks due to their resistance, but also offer an efficient and low-cost production option in the north. Through careful selection, especially when it comes to early growth rates, as well as attention to herd health and nutrition, the Jefferis family can meet the specifications of markets typically supplied by cross-bred or *Bos taurus* cattle.

Buffalo fly

While Brahman cattle are less susceptible to buffalo fly as a result of having less hair, management is still important.

Buffalo fly feed on cattle and buffalo, often causing severe irritation to the host animal (Chapter 13). Rodger has seen cattle continually rub a site of irritation on a post or tree, creating an open wound which attracts even more buffalo fly. This can cause cattle to lose weight and results in reduced milk production among cows.

The Jefferis' Brahman cattle generally show little distress from buffalo fly, an attribute which they attribute to herd selection. Cows which appear to be particularly susceptible or sensitive to buffalo fly are culled.

Buffalo fly are seasonal; they thrive in the wet and their numbers decline in the cooler months. During periods of increased fly activity, Rodger treats bulls with a backline if they are moving through the yards; however, he will not bring them in specifically for this treatment. If left untreated, the bulls may exhibit some mild irritation as a result of the buffalo fly but their productivity is little affected. As there is no apparent productivity cost, the Jefferis family does not treat the entire herd.

The family is vigilant in its management of external parasites but ultimately believes that graziers can greatly minimise the issue and maximise their profitability by breeding cattle that are well adapted to the parasite challenges of their local environment.

Key messages

- Graziers in northern Australia must be vigilant in their control of cattle ticks and buffalo fly.
- Culling cattle that are more susceptible and sensitive to buffalo fly can help reinforce the herd's overall resistance.
- Through choosing to run cattle breeds which are genetically adapted to the climatic conditions of a region, graziers can minimise external parasite management concerns.
- Careful selection pressure for traits such as growth, as well as nutritional management within the Brahman breed, will allow access to all markets.

CASE STUDY 5: MAXIMISING PRODUCTIVITY POTENTIAL

Background

Nigel Alexander is the Chief Executive Officer of the North Australian Pastoral Co. (NAPCO). He is involved with the management of over 200 000 cattle across 13 stations in Queensland and the Northern Territory, a cattle feedlot, 180 employees and more than 6 million ha. The geographical diversification of the stations, together with the feedlot, enables the company to maximise their productivity potential and mitigate the risk of drought.

The company has developed its own composite breed of cattle to complement its production system and consistently deliver to market specifications.

At a glance

- Company: North Australian Pastoral Co. (NAPCO).
- Location: 13 stations across Queensland and the Northern Territory (Fig. 21.11).
- Area: 5 800 000 ha.
- Annual rain: varies from ~400–500 mm on the Barkly Tablelands, 600 mm in the Gulf Country, 800 mm in

Figure 21.11: Location of NAPCO properties. Source: NAPCO (2012).

the Maranoa and as low as 200 mm in the Channel Country.

- Pasture: variable including Mitchell, Flinders and bluegrasses, as well as buffel grass, spinifex and various palatable shrubs.
- Enterprise: Closed breeding of own two composite breeds, the Alexandria and Kynuna composites. Cattle are finished at Wainui feedlot and processed in Australia. 70% of meat is exported and 30% is sold domestically. Total herd of ~200 000 cattle.

A vertically integrated production pathway

Particular properties are dedicated to breeding, growing, backgrounding and finishing cattle. Generally, cattle are bred on northern stations and gradually move south-east throughout their lives, season-dependent. The geographic spread of properties allows cattle to be moved so feed demand can be closely matched to feed supply (i.e. pasture and edible shrub), hence the productive capacity of the country is maximised. The herd can be concentrated in an area in a time of abundance, or dispersed during dry times.

Most NAPCO cattle are finished on grain in Wainui feedlot. This enables the company to provide a consistent product that meets the specifications for its target markets and ensures that cattle are available for sale year-round (Fig. 21.12).

Cattle are processed in Australia by abattoirs with which NAPCO has strategic alliances. NAPCO has concentrated on processing cattle in Australia rather than aiming at the other major market for northern cattle (live export), to minimise exposure to the risks associated with the live trade. Consequently, no NAPCO cattle are exported live.

Figure 21.12: Sorting cattle in the yards.

The majority of exported meat is sold to Japan, followed by South Korea and the USA. Most domestic meat is sold to a major supermarket chain.

NAPCO composite breeds

At its inception in 1877, NAPCO's herd was based on Shorthorn with the only variation being within the Shorthorn breed. In the mid 1980s, NAPCO began the Alexandria composite as a means of capitalising on preferred traits within other breeds, including tick resistance and the ability to thrive in the harsh northern environment, and hybrid vigour.

The Alexandria is a stabilised composite breed made up of five breed types, primarily Shorthorn (for their productivity) and Brahman (for their tropical adaptability), with smaller amounts of Africander, Charolais and Hereford. This composite greatly improved the company's productivity; however, improvements in eating quality were still required. Consequently, in the 1990s, the Kynuna composite was developed to:

- optimise growth rates;
- maximise reproductive rates;
- display environmental adaptation to the heat and dry of the north;
- improve carcass characteristics to meet the requirements of higher-quality meat markets.

The aim was to have a self-sustaining Kynuna herd producing sufficient sires for use with Alexandria composite cows on the northern breeding properties. These would produce terminal progeny for the domestic and export markets. The final Kynuna composite incorporated Brahman, Shorthorn (a higher proportion to improve meat quality traits), Red Angus (for growth and marbling potential) and Tuli (for fertility, adaptability and marbling).

NAPCO now operates a closed herd for its composite breeds: it does not buy in bulls, but rather uses bulls bred through the composite breeding program on one of the NAPCO properties. While this strategy helps ensure biosecurity (freedom from disease) and trueness to type (consistent progeny), it does limit the company's ability to buy in breeders to rebuild numbers following a drought. During such times, NAPCO opportunistically trades cattle without altering the structure of the breeding herd.

Production pathway

The production pathway begins on the northern properties. There, Kynuna composite bulls are joined to Alexandria composite cows to produce terminal progeny for domestic and export markets.

Following the annual mustering program, which involves two rounds of weaning, weaners are transferred to the south-eastern Channel Country and/or central Queensland stations, season-dependent, for backgrounding. The total distance is up to 1600 km (Fig. 21.13).

The cattle generally remain on these stations until they are ready to be finished in the feedlot. For domestic markets, cattle enter the feedlot at ~350 kg liveweight and are on feed for 60–70 days. For export markets, cattle must be on grain for a minimum of 100 days and reach a final liveweight of ~650 kg at slaughter.

Nigel explains that the feedlot has been part of the NAPCO structure since the early 1980s. Initially it was a simple operation, used purely as a drought mitigation tool when feed was limited elsewhere. As market demand evolved, the feedlot has played a more important role and complements the company's composite breeding program. In 2011 NAPCO completed a refurbishment of its feedlot and feed systems, doubling the capacity to ~18 000 head on feed at any one time.

While remaining an important drought mitigation tool, Wainui now allows NAPCO to finish cattle quickly and to market a consistent product of guaranteed eating quality, regardless of seasonal conditions, thus complementing the breeding objective for the composite herd. The feedlot has enabled NAPCO to increase production capacity throughout its entire production pathway and has helped simplify and systemise the production process, which is critical to a company as geographically diverse and as large as NAPCO.

Key messages

- Producing cattle that meet target market specifications is important in running a successful enterprise.
- Composite breeding offers several production advantages including capitalising on the best traits of several breeds.
- Geographical diversification can be a valuable drought mitigation tool.
- Grain finishing as part of a production pathway ensures eating quality and consistent supply.

CASE STUDY 6: INCORPORATING TROPICAL PASTURE SPECIES TO INCREASE PRODUCTION IN VARIABLE SEASONS

Background

Tom Amey has implemented an ambitious 10-year development program which aims to increase carrying capacity and gross income by 50% on his properties near Casino in north-eastern New South Wales.

The key element driving this program is the introduction of various pasture species, including subtropical grasses and legumes, to ensure quality feed is available at all times of the year, regardless of the land type and climate variability.

Figure 21.13: Mustering.

Tom is well on the way to achieving his goal and attributes this to a clear understanding of the soils and microclimates that characterise his properties, the use of pasture species which are suited to them and an understanding of the grazing pressure they can withstand.

At a glance

- Producer: Tom Amey.
- Properties: Dyraaba and Araucaria.
- Location: Casino, north-eastern New South Wales.
- Area: Dyraaba 245 ha, Araucaria 230 ha.
- Annual rain: 1016 mm, summer dominant.
- Enterprise: 250 composite breeder cattle. Yearlings generally sold at ~9.5 months at 180–200 kg HSCW (hot score carcass weight) as MSA (Meat Standards Australia) yearlings.
- Soil: Clay loam, alluvial clay and sandy loams.
- Pasture: Native and naturalised pastures include paspalum, blady grass, couch and carpet grass. Oversown in places with ryegrass, oats and clover. Improved subtropical grasses and legumes.

Matching pasture to land and season

Tom conducted a property assessment which considered soil type, rockiness, slope and frost susceptibility, as the basis of his development program. Land capability was determined and areas identified that are suited to specific pasture species and management techniques. The property is now being re-fenced into land capability units to facilitate the establishment and management of grazing regimes specifically suited to that unit (Fig. 21.14).

Tom recognises the advantages of the overall climate and the microclimates which typify his land. On his property, on any given day of the year, some pasture species will be growing; this is typical in the escarpment country from Gympie in Queensland to around Sydney. Tom intends to capitalise on this to maximise productivity and manage the impact of drought. During the worst of droughts, he needed to destock only his non-performers and could easily maintain the rest of his herd.

Tom increases the productivity of his most productive land (clay loam creek flats) by annually oversowing the naturalised setaria pastures with ryegrass and oats. These species supplement the breeding herd during winter months when growth of the tropical species slows. The high-quality oat and ryegrass pastures, which are fertilised with nitrogen, also encourage the herd to eat the frosted and mature tropical grass species.

Figure 21.14: Matching land class to pasture species helps maximise productivity.

In summer, when pasture supply exceeds demand, the steep, frost-free land is spelled to allow the trailing legumes (that have stems up to 2 m long and can climb associated grasses and fences) to display rapid growth. The legumes crawl over the rank setaria pasture and provide pasture with increased crude protein and metabolisable energy. The creek flats are heavily grazed in late summer in preparation for the oversowing of oats and ryegrass. These are then spelled as the cows graze the steeper pastures until the end of June, when they are moved back on to the ryegrass/oats pastures.

On the sloping land, Tom has slashed the setaria pastures and oversown them with clover. Molybdenum superphosphate is added to aid establishment of the clover. The addition of clover improves pasture quality in autumn, with moderate production during winter and good growth in spring, provided rainfall is at or above average.

This has resulted in an extremely productive pasture with the setaria improving in quality post-slashing and with the addition of clover (Fig. 21.15). Slashed setaria pasture with clover at 40% of the sward has been sampled at 22% crude protein, 11.5 MJ of metabolisable energy and 74% digestibility. Setaria pastures require slashing or heavy grazing during the growing season (summer) to promote new growth and in autumn to allow for clover germination and growth. Setaria >40 cm decreases significantly in feed quality.

Understanding how to manage improved pastures is as important as the improvement itself, and producers must understand a pasture's grazing pressure limits to allow for maximum sustainable utilisation. Tom applies this to his various pasture species and stocks accordingly, ensuring that pastures are sustained and generally benefit from the grazing event (Fig. 21.16).

Figure 21.15: Setaria/clover pasture.

Key messages

- Productivity can be maximised by understanding the features of a property, particularly soil and microclimates, in order to determine what pasture species are suited to that particular property.
- Variations in climate can be compensated for by using pastures that will perform across a range of conditions.
- An understanding of plant response to grazing and species grazing limits is important to ongoing pasture performance.

CASE STUDY 7: MAXIMISING PRODUCTION THROUGH TRADING CATTLE

Background

Cam Munro is the General Manager of Egelabra Merino Stud, which covers 55 000 ha of prime grazing country near Warren in central New South Wales.

The focus of Egelabra is Merino sheep production, with a flock of ~50 000 stud and commercial sheep, cutting an average of 7.5–8 kg of 20.5 micron wool per head. Complementing this enterprise are cattle breeding, trading and cropping operations.

Figure 21.16: A composite breed steer ready for market.

While cattle trading decisions are influenced by available feed and cattle are only purchased if they 'have the feed in front of them', the primary driver of purchasing decisions is economics. As a general rule, the aim of the trading enterprise is to double the money outlaid for the cattle by the time they are sold, generally nine to 12 months later.

The type of cattle traded varies but it usually includes either southern steers from the Victorian weaner sales or cow–calf units from Queensland, the decision being determined by the value they present. 'We consider ourselves opportunity traders,' Cam says.

At a glance

- Manager: Cam Munro.
- Property: Egelabra Merino Stud.
- Location: Warren, central New South Wales.
- Area: 55 000 ha.
- Annual rain: 475 mm.
- Pasture: Lucerne, clover, ryegrass, phalaris and native pastures.
- Enterprise: Merino sheep totalling 50 000 (stud and commercial animals), 1200–1500 cattle breeders (mixed breed), 500–700 trading cattle, 3200 ha wheat, 1600 ha oat and feed crops.

Doing the sums

Despite not being the core business enterprise, cattle trading is an important part of Egelabra's business, from both pasture utilisation and income diversification perspectives.

Cattle are generally not purchased if doubling money within a 12-month period is unachievable, regardless of the amount of feed available. Trading opportunities will be sought in good and marginal seasons, with numbers traded being influenced by the season and buy-in prices.

Cattle are typically purchased in autumn following rain to take advantage of the seasonal increase in feed and sold in late spring and early summer to meet market specifications and marketing opportunities. Cow–calf units or steer weaners are preferred, with the decision of which to purchase based on their potential to meet the above financial objectives.

Over an average 10-year period, cows and calves will be purchased in four of the years as they offer the business more marketing alternatives and better value. In two of the 10 years, steers will be purchased and in the remaining four years, the business will not trade cattle due to prohibitive buy-in prices or a lack of available feed and poor seasonal outlook.

Traded steers are purchased and managed towards particular target markets with predetermined sale dates in mind. Egelabra management will consider changing targeted sale dates and markets only if compelling circumstances arise, such as timely, significant rainfall.

Cows and calves

Queensland is the state of choice for the purchase of cow–calf units, typically offering better value and more cattle than closer New South Wales markets. Cam explains that the cow–calf unit often offers better value than weaner steers.

A decision to purchase cows and calves is based on price and the ability to value-add by eventually splitting the unit. No particular market is targeted; Egelabra management places less importance on the breed and evenness of the line when buying cows and calves than it does with steers. Rather, it utilises the flexibility of the cow–calf unit and markets according to the seasonal conditions (Fig. 21.17). If good autumn and winter rains are received, the business will aim to wean in spring and to sell the heifer weaners, as the business model does not allow for the increased husbandry associated with heifer management.

The steer weaners will be sold if feed availability is limited or if they are from a breed which is more constrained in its weight gain capacity within Egelabra's production environment, such as *Bos indicus* (Chapter 9). Feed and breed permitting, the steer weaners will be grown out and sold through the saleyards or direct to feedlot.

Figure 21.17: Pregnancy-testing cows at Egelabra.

Egelabra will, on occasion, introduce its own Angus or Shorthorn bulls to the cow herd after calving. The cows are then either sold as pregnancy tested in calf (PTIC) if feed becomes tight, or retained on the property for calving (Fig. 21.18).

Steer weaners

Steer weaners are typically purchased from southern New South Wales and the Victorian weaner sales and a premium often paid to secure quality lines. Six- to

Figure 21.18: Shorthorn cows with calves at foot.

eight-month-old Angus, Shorthorn or Hereford weaners are preferred, or a cross including those breeds. The business has found that any additional cost of purchasing a good line is repaid through the improved weight gain and increased marketability of the cattle. The steers are generally sold through an ongoing association with a major feedlot when they have reached feedlot entry weight of 430–500 kg (Chapter 11) after six to nine months.

Egelabra management looks to the south for its weaner steers in March/April because the timing of these sales fits well within its annual cycle of operations. It has also found that these weaners meet the trading objectives of quickly adding condition and trading on.

A word of warning

Biosecurity is always a risk when introducing new stock to a production environment and is therefore an inherent risk of trading. While the risk is relatively low with steers, trading breeding cattle can be problematic as diseases that can seriously affect productivity, such as pestivirus (Chapter 13), can be imported.

While the risk can never be totally eliminated, it can be reduced by:

- finding out as much as possible about the cattle being bought before the transaction is finalised;
- processing the cattle upon receipt with a quarantine drench and vaccination;
- segregating the newly arrived cattle for several weeks until they have settled.

Key messages

- Trading decisions should be based on budgeting.
- How cattle will be on-sold and their marketability should be considered before purchase.
- Flexibility, such as the ability to readily move from steer weaners to cows and calves, is important in a trading operation.
- The temptation to retain stock after they are finished or to alter the target market should be resisted unless compelling circumstances arise, such as significant, timely rainfall.

CASE STUDY 8: UNDERSTANDING FEED REQUIREMENTS AND HEIFER MANAGEMENT POST-WEANING

Background

Rod Manning states that ‘the risk of not maximising the productivity of a beef herd can be significantly reduced by understanding the amount of energy per kilogram of dry matter (MJ/ME kg DM) needed to attain target weights for different mobs of cattle and managing those cattle accordingly’. This is particularly important with heifers, that largely determine the ongoing productivity of the herd.

Rod applies this principle to his grazing operation near Mt Buller in Victoria, where he aims to ensure that enough pasture feed is allocated to cattle to hit critical target weights on time.

At a glance

- Producer: Rod Manning.
- Property and location: Davilak Pastoral Co., Mansfield, Victoria.
- Area: 1200 ha freehold plus 1200 ha on lease.
- Annual rain: 800mm.
- Soil: duplex clay.
- Pastures: ryegrass, phalaris and various clovers.
- Enterprise: 1500 Angus cows and an opportunistic cattle trading operation.

Calving

Central to Rod’s operation is a tight calving period delivered through a short joining period. Condensing the calving period affords easier management of calves at marking and weaning and assists with marketing. Rod joins his heifers for about six weeks and cows for seven, to achieve 60–70% joined in their first cycle.

A condensed joining also provides more options when it comes to selecting heifers for joining the following year. If all the calves are about the same age by virtue of a tight calving, then like can be compared with like, rather than falling into the trap of selecting the biggest (which were born earlier).

A tight joining, however, presents several challenges in that cows and heifers are exposed to bulls for fewer cycles. This means that the cows and heifers must present in optimal condition for joining, which requires nutritional management of cows and weaner management of heifers (Fig. 21.19).

Weaning

Rod aims to wean any spring calving cattle at five months and autumn calving cattle at seven to eight months of age. At this stage of lactation, the higher-quality pasture required to maintain cows and produce a relatively small amount of milk is better consumed directly by the weaned calf. Rod relates such management decisions to attainable

Figure 21.19: Cows with calves ready to be weaned.

kilograms of beef per hectare and allocation of feed to the most productive and profitable cattle.

Calves are yard-weaned (see case study 2), a process which Rod considers the greatest single leap forward in cattle husbandry in southern Australia, enabling cattle to become familiar with yards, water troughs, feeding routines and people (Fig. 21.20). The benefits of yard-weaning are particularly apparent if cattle later proceed to feedlots. In feedlots, yard-weaned cattle tend to:

- accept confinement and go on to concentrate feed and water quickly;
- better tolerate the social, psychological and metabolic stress involved with introduction to the feedlot;
- achieve higher feed conversion rates and weight gains;
- have stronger resistance to respiratory disease;
- accept the presence of people, vehicles and horses.

Figure 21.20: Yard-weaning is considered an essential management practice.

Rod joins five mobs: heifers, first calvers, second calvers, third calvers and then the fourth, fifth and sixth calvers as one mob. A high proportion of heifers are selected to be retained as replacement stock at weaning. This lowers the initial selection intensity but maintains the current herd structure and increases the flexibility of the overall herd by maintaining a balance of ages. It also allows for higher culling pressure over all age groups and the removal of poorly producing females from the herd. Heifers are selected for their potential ability to become valuable contributors by becoming pregnant, delivering and rearing a calf and conceiving again within 45 days of the start of mating, to maintain a 365-day calving interval.

Heifer management

An understanding of energy and protein is required to achieve critical target weights and Rod adopts an HACCP (hazard analysis and critical control points) approach to production. The availability of quality feed is a critical control point and contingency plans are needed to manage the situation and risk; that is, supplementary feeding.

Heifers selected for joining the following year are closely monitored from weaning. Rod aims to manage these heifers to reach a minimum weight of 300 kg at joining, averaging 320 kg, and works backward from the joining date to determine how much feed of a particular quality they will require on a daily basis. As a guide, weaner pastures should contain at least 11 MJ/ME kg DM and 15% crude protein (Chapter 16) to enable desired liveweight gains.

Many producers fall into the trap of allocating stock according to the country's dry sheep equivalent (DSE) rating but Rod believes that this is a retrospective view of conditions, rather than futuristic. Pastures must be monitored regularly, at least weekly, to ensure there is no disruption to heifer growth.

Rod aims to have his heifers in good physical condition with a fat score of ~3.0–3.2, to reduce calving difficulties and ensure a rapid return to oestrus post-calving. Poor nutritional management of heifers before calving can lead to several significant health issues, including:

- dystocia due to inadequate pelvis size for the foetus (often caused from overfeeding the heifer in the final three months of pregnancy);
- predisposition to several metabolic disorders, including milk fever and ketosis/pregnancy toxaemia (often caused from underfeeding the heifer in the last month of pregnancy);

- difficulties during birth potentially resulting in stillborn calves, inability to become pregnant again, inability of calves to thrive, reduced ability of heifers to reach target weight at joining and potentially reduced mature weight.

Even in ideal condition, heifers can experience difficulties at calving and need more supervision than mature cows.

Steers are managed using the same principles and sold to feedlot backgrounders or feedlots depending on the season and market opportunities.

Key messages

- Available energy per kilogram of dry matter of pastures is the main driver of production.
- Working backwards from target weights assists in understanding the daily feed that is required to meet these. Supplementary feeding can make up for shortfalls.
- Feed should be allocated to the class of cattle that will generate the greatest return.

CASE STUDY 9: MANAGEMENT OF TRACE MINERAL SUPPLEMENTS AND INTERNAL PARASITES

Background

The relatively wet climate of the Yarra Valley means that trace element deficiencies, e.g. selenium, and internal parasites are constant management concerns for graziers in the area (Chapter 13). David de Pury runs a cattle breeding herd and has found that weaners require special treatment to be turned-off at 18 months of age.

At a glance

- Producer: David de Pury.
- Property: Yeringberg.
- Location: Yarra Valley, east of Melbourne, Victoria.
- Area: 588 ha.
- Annual rain: 810 mm.
- Soil: 15% alluvial river flats, remainder rolling hills with acidic, silty clay loam derived from Silurian sedimentary rock.
- Pasture: perennial ryegrass, tall fescue and white clover.
- Enterprise: 250 breeder cows. Angus/Shorthorn/Charolais cross; 2200 first-cross breeder ewes, producing 2800 lambs annually.

Managing trace elements

David de Pury had noticed that his cattle were not thriving, despite there being ample pasture on offer. Keen to address this problem, he participated in a Producer Demonstration Site trial, funded by Meat and Livestock Australia (MLA), in which his herd was tested for deficiencies. This revealed that selenium deficiency was a significant issue in his area. Selenium deficiency is exacerbated through increased pasture production, which causes the amount of available selenium per kilogram of dry matter to be diluted (Chapter 16).

When David increased pasture production, he inadvertently exacerbated the selenium deficiency and negatively affected productivity. The soils on Yeringberg are extremely weathered, which contributes to the problem; the cattle on the river flats, which are replenished by the occasional flood, are generally not as deficient as those on the higher country (Fig. 21.21).

The trial results motivated David to begin a selenium supplementation program for his young cattle. This has resulted in improved productivity among the weaners of around 16 kg/head by the time they are sold at 18 months of age. It equates to a $32/head increase, with the supplement costing less than $2/head.

David now treats all young cattle with a long-acting (18-month) subcutaneous selenium injection at marking, but he does not treat the less-affected older breeders.

Since becoming aware of the trace mineral deficiency in his cattle, David also tested his sheep. These proved to be deficient in cobalt as well, similarly exacerbated by increased pasture production.

All lambs are now given a cobalt and selenium injection at lamb marking, which has resulted in increased productivity across the flock. The cobalt deficiency recorded among the sheep has not been found in cattle but David regularly tests a sample of the herd.

Managing internal parasites

Worms are pervasive in wet areas such as the Yarra Valley (Chapter 13) so David no longer conducts worm tests on his cattle, instead routinely treating all young stock at regular intervals. If he does not do so, they quickly begin to exhibit signs of worm infection such as scouring and listlessness.

David drenches his calves at weaning in February, in May at the onset of winter and again in early spring before the majority of the weaners are sold. Heifers that are retained as breeders will be given another drench in the autumn and again at 23 months of age before calving. Second-calf heifers are also drenched at this time. If any

Figure 21.21: Weathered soils can contribute to mineral deficiency in cattle.

of these drenches are delayed, the cattle begin to lose condition, become lethargic and often begin to scour. Heifers are particularly vulnerable and a failure to drench can dramatically affect productivity by leading to weight loss, failure to conceive, poor lactation and even the death of the heifer or calf. Careful attention is always paid to dose rate when drenching cattle (Fig. 21.22).

The result

Through vigilance and careful management, David effectively controls trace mineral deficiencies and internal parasites on his high-rainfall property in the Yarra Valley.

Figure 21.22: Heifers thriving after careful parasite management.

The economic cost of treatment is far outweighed by the productivity gains gained from supplementation and drenching.

Key points

- Awareness of inherent trace element concerns in regional areas is vital in understanding how to maximise productivity.
- Drenching at regular intervals where there is a heavy worm burden can help ensure cattle maintain good condition.
- Livestock should be carefully observed to ensure they are not performing below expectation. Where issues present, timely and appropriate treatment should be provided to ensure cattle meet market specifications.

CASE STUDY 10: GENETICS AND BULL SELECTION TO MEETING BREEDING OBJECTIVES

Background

Libby Creek helps manage Hillcrest Pastoral Co. and advises on bull selection for the property. When selecting bulls for incorporation into the herd, Libby considers the business' breeding objectives and selects bulls accordingly.

The primary objective of Hillcrest is to run a black-coated, composite, self-replacing breeding herd by mating

Angus bulls to Hereford/Shorthorn/Angus cross cows with a view to increasing productivity, creating more marketing options and maximising returns.

At a glance

- Property manager: Libby Creek.
- Property: Hillcrest Pastoral Co. group of properties owned by Hugh and Clare Bainger.
- Location: around Avenue Range between Naracoorte and Kingston in south-east South Australia.
- Area: 5238 ha.
- Annual rain: 500 mm.
- Soil type: clay over limestone.
- Pasture: clover, ryegrass and phalaris.
- Enterprise: calving 2500 females as part of a composite breeding program of Hereford/Shorthorn/Angus cross cows and Angus bulls; 2000 Merinos.
- Composite breeding program.

The selection and breeding objectives guiding the Hillcrest herd development are to breed a black-coated composite female herd demonstrating the best characteristics of the Angus, Shorthorn and Hereford breeds with the added advantage of hybrid vigour. When selecting Angus bulls for Hillcrest, Libby is aiming to introduce animals that, when joined to Hereford/Shorthorn/Angus cross cows, deliver progeny demonstrating the best of each breed in combination (Fig. 21.23).

Finding the right bull

Libby carefully considers the estimated breeding values (EBVs) of potential sires and makes a visual inspection to ensure that the bulls are compatible with the objectives of the breeding program (Chapter 17).

Figure 21.23: Composite cows producing predominantly black progeny.

The key objectives include:

- using positive fat EBVs to increase fat in females, ensuring resilience in most seasonal conditions and creating a lower-maintenance animal (i.e. animals that eat more when feed is available and have increased fat reserves when less feed is available, therefore requiring less supplementary feeding) while maximising the fertility of all females, particularly heifers;
- maximising eye muscle and growth rates to increase the productivity of the herd;
- creating a black herd, via the genetic input from the Angus bulls, to deliver uniformity, maximise marketing options and help meet Meat Standards Australia (MSA) criteria for marbling, fat cover and colour.

EBVs

Libby initially looks at overall Breedplan index values when selecting Angus bulls to ensure a balanced approach. Preference is given to bulls with high fat EBVs. While the average for the Angus breed is −0.1, Libby looks for bulls with a score of at least +0.3.

Other important traits are eye muscle area (EMA), followed by intramuscular fat (IMF) and birth weight. While the Angus breed average for birth weight is +4.5, Libby prefers a rating of between +4.5 and +6.8 for joining to cows and approximate breed average for joining to heifers. Libby believes this helps in producing heavier, more robust calves which will ultimately grow faster, meaning that heifer weaners reach mating weight sooner and first-calf heifers come back into oestrus more quickly after calving.

While supervision is required during calving to minimise the affect of dystocia, particularly with heifers, Libby is confident that the benefits of selecting for a positive birth weight EBV far outweigh the minimal birthing difficulties they encounter.

For growth and scrotal size, Libby looks for above-average values. For days to calving, a more negative value is sought for both cows and heifers so that the next generation is on the ground sooner.

Libby seeks an average EBV for milk; if it is too high, the cows find it difficult to re-breed quickly in a difficult season (Table 21.1).

Structure

Having rated the bulls by their EBVs, Libby visually inspects the preferred bulls to assess their structure. Of paramount importance in their environment, which is characterised by soft ground, are the bull's feet. The claw

Table 21.1: EBVs for an Angus bull

	Calving ease direct (%)	Calving ease daughters (%)	Gestation length (days)	Birth weight (kg)	200 day weight (kg)	400 day weight (kg)	600 day weight (kg)	Mature cow weight (kg)	Milk (kg)	Scrotal size (cm)	Days to calving	Carcass weight (kg)	Eye muscle area (cm^2)	Rib fat (mm)	Rump fat (mm)	Retail beef yield (%)	IMF (%)	Docility (trial)
EBV	+0.9	+0.4	–1.9	+3.6	+41	+86	+102	+83	+18	+2.5	–6.6	+69	+10.5	+2.1	+0.4	+1.0	+3.7	–7
Acc.	84%	73%	97%	98%	98%	98%	97%	93%	85%	96%	68%	88%	80%	89%	89%	81%	80%	95%
Breed average EBVs for 2011-born calves																		
EBV	+0.0	+0.3	–3.1	+4.5	+39	+72	+92	+83	+12	+1.5	–3.2	+51	+3.8	–0.1	+0.0	+0.4	+1.1	+2

Source: Courtesy of Rennylea Angus.

set and angle of pasterns must be correct as there is little rough ground to wear down hooves.

She then visually assesses muscle definition and body conformation, looking for a 'soft' bull (sufficient fat cover) that stands well (i.e. is not 'posty' legged, where leg joints are far too straight with almost no bend), is thick muscled (particularly down the hindquarters) and has a tight pizzle, without too much loose skin. The bull must be of quiet temperament so it and its progeny are safe to work in the yards and are less stressed, leading to a better 'doing' animal.

While it is easy to get caught up in EBV detail, Libby constantly reminds herself that she is looking for an animal that will breed the cattle that will enable Hillcrest to meet its breeding objectives. These breeding objectives must be considered in the context of the base female breeding herd and the environment, and it is important to focus on the main areas where improvement needs to be made. Libby admits that it is unlikely that she will find the 'perfect' bull, but she considers all traits above and selects the best.

Environment

The environment into which the bull will be placed is a major factor when considering both structure and EBVs. Libby explains that the focus on positive fat would be less vital in an environment where good feed was available all year. At Hillcrest, however, the positive fat is a drought-proofing tool for tight seasons and, as it is a grass-finishing system, does not result in overfat cattle (Fig. 21.24).

Before Hillcrest began selecting for positive fat, it experienced significant variability in the ease with which cows were returning to calf. Having selected for positive fat for five years now, Libby is noticing higher pregnancy rates in the younger females coming through the program. Although it varies depending on the season and the mob history, the increase in pregnancy rates in the second calvers is ~5%. The steer progeny of these cows hit the target weights and requirements for MSA earlier, allowing access to a greater range of markets (see Marketing options below).

Figure 21.24: Positive fat cows lay down more fat when feed is available and use it during times of less abundance.

Cashing in on genetic improvement

Hillcrest retains heifers from calving heifers, recognising this as the quickest way to gain flow-through of the most advanced genetics via bull selection. These heifers are then managed as part of the heifer herd and, as long as they are on a rising plane of nutrition at joining, tend to join successfully.

Libby ensures that bulls being used over heifers have an average birth weight EBV. If she were to choose a very low value, small calves would be born; these take longer to grow out. Libby views this as another opportunity for the overall herd to benefit from genetic selection more quickly, as larger heifer calves are more likely to join successfully the following year. There is an element of risk, however, and careful management is required as there is a very fine line between having a good-sized calf successfully born and having birthing difficulties from large calves.

Selection for positive fat is also starting to pay off, with second-calf heifers now consistently getting back in calf, even though they are generally the most difficult animal in any operation to have return to oestrus (Chapter 14).

The general resilience of the entire herd and their overall condition has also improved. This is apparent in the increasing kilograms of beef produced per hectare and the ability to reach target market specifications earlier. This equates to a direct increase in profit for Hillcrest Pastoral Co.

Marketing options

One of the main benefits of the composite breeding and bull selection approach has been the production of versatile steers and heifers that can be marketed into a range of markets, including:

- selling through saleyards as weaners at 10 months of age;
- supplying to feedlots as EU steers, 480–520 kg liveweight, 14–18 months of age;
- supplying directly over the hooks to abattoirs as EU steers, 270–320 kg carcass weight, 14–18 months of age;
- supplying directly over the hooks to abattoirs as part of the MSA program, 270–340 kg carcass weight, 14–18 months of age (Fig. 21.25).

Figure 21.25: Steers are being bred to meet market specifications sooner through attention to Breedplan EBVs.

Hillcrest maximises its annual returns by adjusting stock numbers entering each market according to seasonal conditions, the condition of the animals and market prices.

Key messages

- Consideration of both EBVs and visual structure is important in bull selection.
- Breeding objectives and an understanding of the desirable female herd characteristics or profile for the target market give producers a clear goal.
- The environmental conditions affect the suitability of specific traits in different regions.

CASE STUDY 11: MAXIMISING MATERNAL PRODUCTIVITY

Background

Richard McFarlane runs 700 breeding cows and trades up to 1000 steers annually on his property, Wellington Lodge, near Tailem Bend in South Australia. He aims to wean as many calves as possible by maximising the maternal productivity of his cattle operation while minimising operating costs. Richard pursues this goal through an early weaning program which enables him to wean before joining, which is all conducted via artificial insemination (AI).

At a glance

- Producer: Richard McFarlane.
- Property: Wellington Lodge.
- Location: Tailem Bend, South Australia.
- Area: 7500 ha.
- Annual rain: 380 mm.
- Soil type: sandy loam limestone through to black salty flats.
- Pasture: clover, ryegrass and phalaris.
- Enterprise: joins 700 cows via AI annually; trades 1000 steers and heifers annually; can have up to 2500 cattle on property.

Maximising maternal productivity

Richard McFarlane focuses on several key animal husbandry practices to maximise the productivity of his cows. From genetic trait selection as part of 'Team Te Mania', a partnership of Australian beef cattle producers who work together to produce high-quality beef cattle and collectively market through a nationally recognised brand, through to early weaning before joining, Richard works to minimise costs and maximise returns.

Artificial insemination

All 700 of Richard's breeding herd are AI-ed through a time-fixed program with Team Te Mania genetics. Richard is a keen advocate of AI for various reasons.

- Condensing the calving period.
  A condensed period over which calves drop following a time-fixed AI program has benefits from a management perspective as Richard and his family must weigh, tag and ring male calves the day they are born as part of the arrangement with the Te Mania Team. It also benefits the growth rates of calves, allowing them to spend as much time as possible with their mothers before they are weaned at 85 days from the main calving date.
- Genetic selection.
  The AI process allows Richard to preferentially select for genetics which will influence maternal productivity. such as high indices for gestation length (meaning a longer gestation period) and early growth weight (200 days). This has resulted in strong calves with the ability to develop and gain condition quickly.
- Insurance policy.
  Richard seeks to maximise his enterprise's calving percentage by running Te Mania Team progeny test bulls with his cows immediately after AI as an insurance policy. These bulls are the backup rather than primary source of insemination. Richard finds that ~70% of cows conceive through AI, meaning that far fewer bulls are required to cover the 30% of cows that did not conceive to AI than would be the case if all cows were conventionally joined. Consequently, less

time and money needs to be invested sourcing bulls; the effort focuses instead on sourcing appropriate AI genetics.

- Cow management.
  Cows are closely managed to maximise their maternal productivity.

Joining post-weaning

Calves are weaned at 85 days of age and cows are kept in the yards. Controlled internal drug releasing devices (CIDR) hormone implants are inserted in the cows to initiate oestrus synchronisation. These are withdrawn after 10 days and the result is a tight synchrony of oestrus and the cessation of lactation. Cows are then AI-ed. This joining post-weaning has resulted in a 10% increase in weaning percentage, to over 90%.

Three calvings per year

Dividing the breeding herd into three mobs for joining at various stages throughout the year makes the herd easier to manage. The smaller mobs are easier to handle at AI and the backup bulls, leased for $2000/year, have a much better chance of servicing the smaller mobs. Essentially these bulls now complete three joinings a year, not one. The three joining/calving periods mean there is an ongoing but less seasonally intense demand on labour and facilities throughout the year. It also allows for three annual marketing periods, hence spreading associated risks, such as price and market fluctuations, across the year

Weaner management

When calves are weaned most weigh 105–110 kg (Fig. 21.26). Light calves weighing 80–90 kg are left on their mothers and weaned later, at which time all late-calving cows are culled to maintain a tight herd structure.

Weaners are moved to a small feedlot for 30–40 days to ensure ready access to a high-quality diet and promote rumen development through the provision of a mixed ration of barley, lupins, some minerals and cereal hay (Fig. 21.27). To minimise time and labour costs, Richard introduced a self-feeder for the grain; however, this led to a daily weight gain of only 0.4 kg as opposed to 1 kg/day which was the average when grain was poured into troughs. Richard is investigating this management issue but, with three weaning periods annually and a 30–40 day period post-weaning in the feedlot, the labour requirement is significant. Richard has found that the feedlot system greatly improves the weaners' ability to gain condition – when similar weaners were put directly into paddocks they took longer to move forward and required more attention.

When four to five months old, weaners leave the feedlot and are put into small cells of fresh lucerne and trained onto a single-wire electric fence. These paddocks are located close to the homestead, for ease of management. Training takes two weeks, after which time the weaners enter an intensive two-day rotation program on lucerne cells.

Early weaning has resulted in weaners taking about two months longer to reach feedlot entry weight than with

Figure 21.26: Tight calving patterns through AI assist with weaner management.

Figure 21.27: Weaners on feed.

later weaning; however, the benefits far outweigh the minimal costs (i.e. labour) associated with carrying the cattle for an extra two months. Ultimately, these cattle are turned off between 18–19 months at 450–520 kg, averaging 480 kg. Richard could hasten the process but it would require the supplementary feeding of heavy cattle, with additional labour and management requirements. While this can be managed for weaners and is relatively inexpensive, to continue the extensive supplementary feeding approach in older cattle would be difficult and expensive. Furthermore, Richard has an assured buyer (Ranger's Valley) under the current arrangement.

Ranger's Valley Abattoir pays the $100/head transport cost, on top of the value of the cattle, to transport the cattle to its facility in northern New South Wales. It is consistently impressed with the quality of the carcasses and marbling. Ranger's Valley provides individual carcass feedback, which assists in Richard's management and adds value to Team Te Mania.

Heifer management

Richard views his heifers as his most modern and valuable genetic source and is keen to join them as early as practical. Heifer calves undergo the same weaning process as the rest of the mob and are integrated into the cow herd at ~15 months of age when the CIDR synchronisation process begins. In addition to management ease, this has the benefit of exposing the heifers to pestivirus and allowing them to develop immunity before mating. The only 'special' treatment the heifers receive is allocation to the paddock with the most abundant feed, following AI.

Early weaning increases the ease of heifer and second-mated heifer management, and helps in maximising their maternal productivity. Taking the calf off the cow at ~85 days enables the cow to quickly regain condition before the calf begins to draw significantly upon her reserves. This increases the likelihood of that cow getting back in calf quickly. The benefit is particularly obvious in the first-calvers, which would otherwise lose condition rapidly.

Key messages

- Early weaning, if properly managed, can improve the maternal productivity of the herd.
- Joining soon after weaning can help maximise maternal productivity.
- Dividing a breeding herd to calve at different times of the year can reduce management requirements to a more consistent and easier level.

CASE STUDY 12: PASTURE UTILISATION AND STRATEGIC GRAZING

Background

Phil and Nicole Chalmer and their son Rohan operate a cattle breeding and trading operation near Condingup in Western Australia, 60 km east of Esperance (Fig. 21.1). The area of 1900 ha consists of sand to a depth of 0.6–3 m over clay.

The focus of the operation is maximising pasture utilisation through strategic rotational grazing (Chapter 15) in an effort to ensure the enterprise is as productive and profitable as possible. The Chalmers aim to produce 1 kg of liveweight per ha for every millimetre of rain that falls on their property, Coronet Hill, which equates to 620 kg of liveweight per ha or 1178 t of beef in total in a year with average rainfall.

The Chalmers either grow their cattle for sale direct to processors, for live export or for feedlot entry depending on potential returns and seasonal conditions.

At a glance

- Producer: Phil and Nicole Chalmer.
- Location: Coronet Hill, Condingup, Western Australia.
- Area: 1900 ha.
- Annual rain: 620 mm.
- Enterprise: Breeding and trading cattle. 700 Angus breeders and 2800 weaners or trading cattle.
- Pastures: Subterranean clover, serradella, ryegrass, capeweed, brome grass and sown kikuyu.

Rotating to better utilisation

The Chalmers aim to produce 1 kg of beef per hectare for every millimetre of rain that falls on their property. With an annual rainfall of 620 mm, this means 620 kg of beef per hectare. The district average is 180 kg beef/ha.

The Chalmers have taken several steps to improve their productivity and have already increased their production to 400 kg beef/ha. They have done this through the opportunistic trading of cattle and the implementation of a rotational grazing system which enables more intensive pasture utilisation.

The Chalmers have divided previously set stocked paddocks of 400 ha into 10–20 cells. Each herd of cattle (300–400 head per herd of yearlings, of which there are eight mobs; 150–200 cows per herd, of which there are three mobs) is assigned 10–12 cells. In an average season, each mob remains in a cell for three days before being moved to the next. There is flexibility to alter this rotation and reduce or increase numbers in variable seasons. A water trough is assigned to each mob and is moved with the cattle, then plugged into a 5 cm high-flow watering point within each cell. The availability of good quality water is critical to a successful rotation system.

The Chalmers have chosen a low-cost rotation model which suits their business operation. Fences comprise one or two electric wires which can be lifted to allow cattle to move from one cell to the next (Fig. 21.28).

Phil explains that although changing to rotational grazing is a significant step, it can be implemented gradually and positive results are often seen in the first year. The Chalmers initially converted 120 ha of their property to rotation and added ~350 ha in each of the subsequent three years. They now have ~70% of their property (1300 ha) under rotation.

Training cattle

In order to maximise the efficiency of the grazing system, the Chalmers train their cattle to electric fences: having

Figure 21.28: Cattle graze cells and are contained using fences with one or two electric wires.

trained, quiet cattle is critical to successful rotational grazing. The process involves introducing new cattle to a small area enclosed by a powerful electric fence, which teaches the cattle to respect fences and not challenge them. Once trained to the electric fence, the cattle are moved through the rotation, thus completing the training process. Experience has shown that cattle trained in this way move themselves into the next cell when the fencing is modified to allow them to do so, minimising the labour requirement and maximising productivity (Fig. 21.29).

The Chalmers' approach to handling and moving cattle is based on the principles of low-stress stock handling (Chapter 13). Cattle are coaxed rather than pushed in the desired direction.

Focus on the pasture

The pasture on Coronet Hill is a mixture of winter annuals including subterranean clover, serradella, ryegrass, capeweed and brome grass to which they have recently sown a summer active perennial, kikuyu.

The sandy soils are naturally acidic (pH 4.5–4.7) and 1.5 t/ha of lime is applied to ~25% of the property each year to elevate the pH. Where lime has been applied, the pH is 4.8–5.3 and rising, according to soil tests which are conducted annually.

To maximise pasture growth, the Chalmers apply fertiliser at a rate of 200 kg/ha superphosphate, 30 kg/ha potash and two applications of 70 kg/ha urea annually over the rotationally grazed country. The set stocked country receives 150 kg/ha superphosphate and 30 kg/ha potash annually. The difference is due to the less intensive utilisation of the set stocked country.

In order to manage risk, it is important to be able to project how much feed will be available in 30 days' time. This allows forward planning and the development of contingency plans should the season suddenly tighten. MLA's feed demand calculator and rainfall to pasture growth outlook tool (MLA 2012a, b) assist with this.

Through the use of these tools, visual pasture inspection and regular (four- to six-weekly) weighing of cattle, the Chalmers can quickly offload or purchase stock to maximise the utilisation of pasture.

In most seasons, the Chalmers have found that they tend to purchase trading cattle in autumn and sell them over summer. If feed is predicted to be particularly limited, they will oversow some pastures with cereals to use for grazing over winter.

Aligning feed availability with target market

The Chalmers adopt a flexible approach, influenced by seasonal and market conditions, to the marketing of their final product.

In September and October, the Chalmers assess the available pasture, correlate this with the seasonal outlook and plan accordingly. In good years, they target the most lucrative market. When feed is predicted to become

Figure 21.29: Cows before calving in autumn, moving into a new cell through an opening in the single-wire electric fence created by lifting the wire with a non-conductive pole.

limiting, they access markets that allow them to destock sooner rather than later.

Sale animals are generally directed to one of three markets:

1. live export – cattle are drafted according to size and breed, with cattle weighing 300–350 kg generally suitable for live export (Chapter 12). This market is ideal in tighter years as cattle can be offloaded sooner at lighter weights;
2. finished cattle sold over the hook – cattle are carried through to 450–500 kg to meet specifications (Chapter 3). This is achievable in good seasons;
3. cattle for feedlot entry – an attractive market when the feedlots are offering good prices (Chapter 11). Cattle may be supplementary fed to meet this market if the price justifies the expense. Target weights vary, based on the feedlots weight/rate grid, so management of the cattle to meet the market is varied accordingly.

Working as a team

The Chalmers' confidence in trying new systems, such as rotational grazing, is partly attributable to the Beef Profit Partnerships group that was established in the Esperance district in 2007 (Beef CRC 2011). This forum enables farmers in the district to workshop and review their systems alongside others in similar situations. The Chalmers have found the group to be a valuable sounding board and benchmarking tool.

Key messages

- Budgeting enables producers to determine whether new systems, such as rotational grazing, will be profitable to their enterprise.
- Provision of ample, good-quality water is essential in a rotational grazing system.
- Low-stress cattle handling can increase the efficiency of rotational grazing systems.

CASE STUDY 13: PRODUCERS WORKING TOGETHER

Background

Producer groups are recognised as an effective and increasingly important delivery mechanism for extension and a pathway to encourage adoption of best practice and research and development outcomes.

Peter Ball is the Extensive Agriculture Industry Development and Extension Leader at the Tasmanian Institute of Agriculture, which is part of the University of Tasmania. He has worked as an extension officer in the field of pasture and grazing management for more than 15 years and has been involved with convening and working with producer groups. Peter recognises the opportunity that producer groups present as well as the merits of varied group structures.

At a glance

There is no set structure which producer groups must follow but Peter has found four common structures:

- committee-led – an executive committee is elected from within the group. This structure tends to operate successfully as all members have the opportunity to influence the group through their elected committee;
- discussion groups – often strongly based on an external coordinator who drives the group, and an activity such as a trial site. Discussion groups can also be based on a specific purpose, such as a supply chain group;
- productivity groups – a looser structure, more group-driven than leader-driven. They meet more on a need-to-meet basis rather than at regular intervals, with a planned approach to an activity;
- training/activity based groups – groups that convene for a specific purpose and may or may not be ongoing.

Producers working together

Peter has seen increased interest in producer groups, which he attributes to growing awareness of the support, understanding and opportunity that such groups offer.

While producer groups are not for everyone, with a group of like-minded producers and someone prepared to take leadership, they offer valuable support, insight and benchmarking opportunities to participants. The groups become a sounding board, a reminder for action and a means of connecting with a diverse range of information and views often available within a network (Fig. 21.30).

Committee-led producer groups

Peter cites the example of a producer group on King Island in Bass Strait, which is self-driven and successful in what it pursues and which has been running for 15 years. A legally incorporated body from inception, the group includes an elected committee which organises events and provides leadership for the 50–85 members. Success is assisted by the small geographic boundary, which results in a strong community spirit and encourages producers with common enterprises and production purposes.

Figure 21.30: Producer groups provide a mechanism for the extension of best-practice principles and research outcomes.

The committee is elected from within the group, hence every member has a sense of ownership. In return, every committee member feels a sense of responsibility to those who elected them. Strong relationships and a sense of obligation are created.

The King Island producer group acts as a key representative body for the island's beef producers. It has worked consistently to build relationships through supply chains and provide advocacy to government for both producer and community issues. Working with processors, it has sought to add value to their product with quality assurance, promoting the brand to customers and consumers and cooperatively trialling solutions to constraints on seasonality of supply. The group also organises forums to bring high-quality information and learning activities to members.

Membership of the King Island producer group involves an annual subscription fee ($50) which contributes to costs associated with incorporation and administration. Additional moneys raised support group activities and are complemented by funding from various industry bodies. Subscription enhances group capacity and mutual obligation.

Discussion groups

Discussion groups are common, generally based on a central coordinator who is either a natural leader from within the group or a paid leader, such as a facilitator, who will coordinate as required.

Discussion groups usually have 15–20 locally based participants and the success of a group is generally linked to its coordinator's ability to take the lead. Members tend to have a strong social bond with a well-established element of mutual trust.

Another form of discussion group can be supplier or alliance groups, which involve producers that may be more geographically spread. These groups tend to involve a paid facilitator.

Topics for discussion are determined by the group and tend to focus on local issues or activities, such as crop or cattle productivity trials, with participants meeting every four to six weeks to review and discuss findings. Activities and trials may be funded through grant money from industry bodies such as Meat and Livestock Australia.

Productivity groups

The structure of a productivity group is less formal and may not involve a designated leader. In Peter's experience, however, the most effective groups are those that have a core membership who are prepared to take leadership roles.

Productivity groups may meet more sporadically than discussion groups as they may not be focused on a central ongoing activity, such as a production trial. Rather, these groups will organise a plan of activities and base their meetings on these. Activities may include field days or courses dealing with topics relevant to local productivity. Benchmarking can be another component of the productivity group, and it occurs more frequently in this forum than in a discussion group.

Participants often do not pay to be involved in production groups but contribute as required for activities, such as paying to attend a course. Group members often lobby for funding from various bodies, such as the state government or natural resources management board, for relevant courses and to initiate local trial activities.

Training or activity-based groups

Training or activity-based groups are commonly smaller, with up to 10–12 participants, and convene for a specific purpose and duration.

Participants may be drawn from the above group structures or separately and they usually pay a fee for a training service provided by a paid facilitator or trainer.

Such groups are naturally bound by a strong common interest and purpose that can enhance the learning potential (Fig. 21.31). In some cases, a group will continue post-training or activity; however, they often dissolve at the end of the course if they are not already part of an existing group. Despite this, they are a powerful learning mechanism.

Producer group keys to success

Peter Ball believes successful producer groups are characterised by several distinctive features:

- they strive to improve the productivity, profitability and sustainability of their members, who tend to have a common purpose and bond;
- groups with a designated leadership tend to be more efficient and effective than those without. In the absence of such leadership, there is a tendency to lose focus and hence members;
- successful groups deal with issues which are relevant and of interest to participants and involve them in setting the group's agenda;
- members of the group need a unified purpose, whether it is promoting a regional difference, a specific issue or a trial site;
- strong regional relationships tend to be the driving force for participation in all the groups and there must be a strong relationship between individual members and between members and the coordinator.

Participants find producer groups valuable for support, benchmarking and education. Such groups are

Figure 21.31: Groups of like-minded producers benefit from shared learning on topics of mutual interest.

increasingly common across rural Australia and continue to attract keen participants in a changing extension and training environment.

The producer group concept also appears online, thereby attracting a broader membership base with a more diverse agenda. While the online group model remains largely untested, it may help overcome some of the major accessibility issues that curtail the expansion of many producer group models.

Key messages

- Producer groups across rural Australia offer support and drive to improve the productivity, profitability and sustainability of their members.
- Various structures exist in different regions.

To be as successful as possible, such groups require a unified purpose, strong leadership, solid relationships between members and ownership by members.

REFERENCES

Beef CRC (2011) *Beef Profit Partnerships*. <http://www.beefcrc.com/documents/publications/beef-profit-partnerships/BPP-Magazine2011-web.pdf>.

BOM (2012) *12-monthly Rainfall Totals for Australia*. Bureau of Meteorology, Canberra. <http://www.bom.gov.au/>.

MLA (2012a) *Rainfall to Pastures Outlook Tool*. Meat and Livestock Australia, Sydney. <http://rainfall.mla.com.au/>.

MLA (2012b) *Feed Demand Calculator*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/Feed-demand-calculator>.

MLA (2012c) *Stocking Rate Calculator*. Meat and Livestock Australia, Sydney. <http://www.mla.com.au/Publications-tools-and-events/Tools-and-calculators/Stocking-rate-calculator>.

NAPCO (2012) *Location of NAPCO Properties*. <http://www.napco.com.au/images/properties/2011%20Map.jpg>.

Glossary

ABARES: Australian Bureau of Agricultural and Resource Economics and Sciences.

Accuracy: correlation between an estimated breeding value (EBV) and the true breeding value which cannot actually be observed.

Activity: a particular method of producing a commodity. More specific term than enterprise, e.g. spring wheat, winter-fattened steers.

Activity gross income: the total value of the output of a farm activity, whether the output is sold or not.

Activity gross margin: activity gross income minus the variable costs of that activity.

Activity gross margin planning: a procedure whereby activities are selected sequentially on the basis of the highest gross margin from a unit of only one key constraint, usually land.

Acute ruminal acidosis: an acute condition characterised by a ruminal pH <5.0 for over 2 hours/day and associated with high levels of lactate acid in the rumen liquor.

ACV: Australia Cattle Veterinarians, a special-interest group which belongs to the Australian Veterinary Association.

Adaptive cycle: cycle of social–ecological system disruption and renewal.

Adult equivalent (AE): northern Australia cattle carrying capacities are calculated on the basis of adult equivalents. An adult equivalent is a 440 kg male or female beast. Carrying capacity is defined as the number of hectares required to support an adult equivalent.

Aged cow: cows older than 10 years.

Ageing: the process of meat tenderisation that occurs over time; it commences after rigor mortis.

Agribusiness: businesses that are closely related to agricultural production activities.

AI: artificial insemination.

Alternative stable states: different ecosystem or social–ecological system configurations, each of which is plausible in a particular environment.

American breeds: composite cattle breeds developed in the USA where Brahman influence exists, Beefmaster, Braford, Brangus, Santa Gertrudis, Simbrah etc.

Amortised loan: a loan that is repaid in equal instalments of principal and interest, with the interest and principal components of the repayment instalment varying as the loan reduces.

Amplifying (positive) feedback: feedback that augments changes in process rates and tends to destabilise a system. It occurs when two interacting components cause one another to change in the same direction (both components increase or decrease). It is synonymous with positive feedback.

Annual grasses: grasses that complete their growth and production within one year.

Annuity: a sum of money received or used every year that is equivalent to a larger sum at the present time or at a future time, e.g. the equal annual sum that repays the interest and principal on an amortised loan. An annual sum over a number of years that is equivalent to the net present value of an investment project that runs over the same number of years.

Anorexigenic: causing appetite suppression.

Anthropocene: new planetary epoch beginning with the advent of industrialisation, characterised by global processes that are strongly shaped by humanity.

Apigmeted: free from pigment.

Arbovirus: this is an acronym of *ar*thropod-*bo*rne viruses, which are transmitted by biting insects. Examples in cattle include bovine ephemeral fever and Akabane disease.

Ataxia: neurological lack of coordination of voluntary movement.

Average daily gain (ADG): daily rate of liveweight gain in kilograms.

Backgrounding: an intermediate stage of production where cattle are fed, managed and grown out to a weight that qualifies for entry into a feedlot. Some cattle operations specialise in backgrounding.

Backline: a veterinarian chemical applied along the backline of cattle.

Balanoposthitis: inflammation of the glans (head) penis and prepuce, commonly referred to as pizzle rot or sheath rot.

Bantu cattle: A breed combining *Bos indicus* and *Bos taurus*, favoured by the indigenous Bantu people of southern Africa.

Biodiversity: the number and variety of genes, species and ecosystems in an area.

Biodiversity conservation: management to maintain or enhance the variety of naturally occurring genes, species and ecosystems in an area.

Biosecurity: preventative measures designed to minimise the risk of introducing a disease to a farm.

Biosphere: the planetary ecosystem.

Black globe temperature: used to measure radiant heat. It consists of a thermometer with its bulb or sensor located at the centre of a matt black copper bulb.

Blepharospasm: spasm of the eyelids, eye squeezed shut.

Body condition: visual differences of both fat and muscle.

Body condition scoring: an established, non-invasive technique used to determine body condition. It is an important assessment of the live animal for suitability to meet prescribed market specifications. The most common Australian scoring system is on a scale of 1 (very poor) to 5 (overfat).

Bos indicus: breeds of cattle originating from the Indian subcontinent; sometimes called Zebu breeds; includes Brahman and Sahiwal.

Bos taurus: temperate British and European breeds of cattle, e.g. Hereford, Angus, Charolais.

Bovine spongiform encephalopathy (BSE): commonly known as mad cow disease.

Boxed beef: meat cuts from the carcass bulked within a small container for retail sale.

***Brachiaria* sp.:** species of tropical forage that were imported from Africa and introduced into Brazil in the late 1960s. It now represents the most important forage source used by grazing cattle in Brazil.

Brahman: a breed developed in the USA mainly from importations of Zebu cattle from Brazil, with two distinct types emerging. The Red Brahman was primarily a mixture of Gir and Indo-Brazilian and the Grey Brahman a mixture of Guzerat and Nellore breeds.

Brand: a label on a product that identifies its supplier and that may have positive or negative associations for customers. Brands are most important when pertinent product attributes are hidden, such as freshness, tenderness, taste or organic status. Brands are less common for fresh foods than for any other product category.

Break-even analysis: testing key elements of a budget of a proposed change to a system to determine the level at which key elements of the proposal make the overall result just equal to the result from an alternative action.

Breeding: as in breeding operation.

Breeding objective: an operation's definition of the 'ideal' animal that the production system aims to breed.

Breedobject: a computer software package used to derive beef breeding objectives by weighting traits in the selection program for their relative economic values.

Breedplan: Australian beef genetic evaluation system that estimates the genetic merit of animals for economically important traits.

Broadacre farms: land suitable for farms practising large-scale crop and/or grazing operations.

Brood cows: mature female beef cattle used as breeding stock to provide beef calves.

Brucellosis and tuberculosis eradication campaign (BTEC): in 1970, industry and the state, territory and federal governments united to form the BTEC. Tasmania was the first state to be declared *B. abortus* free, in 1975. The last state, and hence Australia, was declared free in 1989. Data for bovine brucellosis is displayed on a national website to meet international obligations for animal health monitoring and compliance (www.aahc.com.au).

Budget: a detailed statement of a future plan of action detailing the expected costs and benefits.

Budget control: the process of comparing the actual performance of an aspect of farm production against the performance that was expected when the budget was drawn up.

Buffalo fly: *Haematobia irritans exigua* is a nuisance fly in northern Australian beef production enterprises which can affect productivity.

Bull beef: usually produced by rearing bull calves originating from the dairy industry. This is a specialist market and has, at times, been a substantial market for Holstein calves. Typically, dairy bull calves are purchased at about 12 weeks of age and slaughtered some 15 months later.

Bush encroachment: the change in vegetation from grassland, grassy woodland and grassy forest to shrubland or scrubland, shrub woodland and shrub forest, respectively, due to overgrazing, altered fire regimes or climate change.

Business health: the state of and prospects for profit, financial viability and growth of a business.

By-products: products derived from agricultural processing of grains (corn, soybean, cotton), orange and sugarcane and that are suitable for cattle feeding. Examples include soybean hulls, cottonseed cake, citrus pulp, sugarcane bagasse etc.

Calpains: endogenous cysteine proteases activated by Ca^{2+}. They are components of the enzyme system acting on cytoskeletal proteins during meat tenderisation.

Capital: items that contribute to production over at least a medium time period, such as more than a year. For example, tractor, land, lime fertiliser, infrastructure and equipment.

Capital gains: increase in the value of capital items due to a rise in their market value.

Capital investment: funds used to acquire assets, such as equipment, land or stock, or used on improvements that have a life of more than one year and that add to the productive capacity of the farm.

Cash flow: the movement of funds in and out of the hands of an enterprise or individual farmers.

Cash flow budget: a budget of the expected cash in (receipts) and cash out (payments) associated with a particular farm plan.

Catchment management: the planning and implementation of natural resource interventions to achieve sustainable land and water use in a watershed.

Cattle futures contracts: standardised agreement between two parties to buy or sell a specified product (cattle) of standardised quantity and quality for an agreed price where delivery and payment occurs at a specified future date. In the USA, *live cattle* contracts refer to feedlot cattle ready for slaughter and are based on 40 000 lb (18 143.7 kg) units of cattle with carcass grades of 55% Choice, 45% Select and Yield Grade 3; *feeder cattle* contracts refer to cattle 650–849 lb (295–385 kg) weight range and are based on 50 000 lb (22 679.6 kg) units of Medium and Large No. 1 or Medium and Large No. 1 and No. 2.

Cattle raising (Brazil): activity where a rancher buys weaned calves and stocks them on pasture until they reach a bodyweight of 350–380 kg. From this point, the animal is called a 'garrote' or 'boi magro'.

Cattle tick: *Rhipicephalus (Boophilus) microplus* is a tick common to cattle in northern Australia, which can affect productivity.

Cell grazing: intensive time-controlled grazing where the rest period is long compared to the duration of grazing.

Character: biological characteristics actually measured in selection programs for estimation of breeding values. These are the 'traits' that comprise the selection criteria.

Closed herd: a herd where the only cows and bulls used within the herd are bred within the herd. No external genetics are introduced.

Cobb–Douglas function: in its most standard form for production of a single good with two factors, the function is:

$$Y = AL^{\beta}K^{\alpha}$$

where: Y = total production (the real value of all goods produced in a year); L = labour input (the total number of person-hours worked in a year); K = capital input (the real value of all machinery, equipment and buildings); A = total factor productivity; α and β are the output elasticities of capital and labour, respectively. These values are constants determined by available technology.

Command-and-control: the approach to natural resource management where goals are achieved by active intervention and unending control or manipulation of the physical and biological components of a social–ecological system to produce a particular state and output indefinitely into the future. It invariably decreases system resilience by reducing the range of natural variation and adaptive capacity for the system to respond to disturbance.

Commercial: cattle producer that sells steers, heifers and cull cows and so is focused more on beef production. Almost all the genetic improvement in their herds comes from purchasing bulls from seedstock suppliers.

Commercial cow–calf operation: animals are not registered with herd societies or associations and young steers and heifers are commonly sold shortly after weaning at six to eight months old.

Commonwealth Scientific and Industrial Research Organisation (CSIRO): the national government body for scientific research in Australia. It was founded in 1926 as the Advisory Council of Science and Industry.

Comparative analysis: comparison of the performance of a particular farm with some 'standard' level of performance. (Usually the 'standard' is the average performance of a group of broadly similar farmers.) 'Benchmarking' is a term used to describe a similar approach.

Complex adaptive system: a system whose components interact in ways that cause the system to adjust ('adapt') in response to changes in conditions.

Composite: a breed resulting from the mating of two or more existing breeds, with animals then selected from within the progeny to continue the breed.

Composite breeds: breeds of cattle derived from a composite breeding program.

Compound interest rate: the rate of interest used in compounding.

Compounding: the way a sum of money grows to a larger sum by adding interest, then reinvesting the larger sum to earn interest again, i.e. calculation of the equivalent future value of a present sum.

Confined animal feeding operation (CAFO): a location where animals are confined and fed complete diets for accelerated growth and fattening.

Conservation phase: phase of an adaptive cycle during which interactions among components of the system become more specialised and complex.

Contingency allowance: allowance included in budgets to cover unexpected costs.

Contract growing: refers to forward selling contracts negotiated between a cattle producer and a buyer. Contracts are most frequently established with producers to supply feeder stock to feedlots, butchers or large supermarket chains.

Contractile proteins: actin and myosin, which form the thin and thick filaments of skeletal muscle. These two proteins interact chemically to form actomyosin, which gives muscle the ability to contract and relax. Associated with actin are the proteins, troponin and tropomyosin.

Controlled internal drug-releasing devices (CIDR): used for oestrous synchronisation. They are T-shaped devices with a silicone-coated nylon core. The silicone coating is impregnated with progesterone.

'Convenience' marketing strategy: the targeting of market segments that are mainly concerned to acquire specific attributes of products. These may be related to meat-eating experience (tenderness, taste), production regime (organic, biodynamic), animal welfare, slaughter (halal, kosher) or distribution outlet (local butcher versus supermarket). It is also called 'differentiation'. The emphasis in the business and value chain is on ensuring the presence of relevant attributes, while keeping prices acceptable but not the cheapest.

Cooperative Research Centre (CRC): an Australian federal government program that funds key bodies for Australian scientific research. The CRC Program was established in 1990 to enhance Australia's industrial, commercial and economic growth through the development of sustained, user-driven, cooperative public–private research centres aimed at achieving high levels of outcomes in adoption and commercialisation.

Core discipline: an integrating body of knowledge. The discipline integrates knowledge from many disciplines into comprehensive understanding, analysis and explanation. The core discipline of economics makes it possible to understand, analyse and explain the operation of a whole-farm system.

***Corpus luteum* (CL):** commonly called the yellow body, it is a yellow to orange structure that forms on the ovary at the site of ovulation of the follicle. The CL produces mainly the hormone, progesterone.

Corridor (wildlife): an area of habitat connecting wildlife populations otherwise separated by human-dominated landscapes unsuitable for wildlife.

Cost of gain: the cost of putting on weight due to feed and associated incurred costs (vaccinations, medications, insurance etc.), expressed in c/kg or $/lb (0.45 kg) or per 100 lb (45.4 kg) bases. It is influenced by feed costs, efficiency of weight gain and health.

Cost–price squeeze: the phenomenon of farmers' real costs for their inputs rising and prices they receive for their products being static, falling or rising at a slower rate than real costs. It means farmers have to increase their productivity to remain profitable.

Cow–calf operation: farms that have cow herds with the primary goal of producing calves, commonly for sale shortly after weaning.

Creutzfeldt–Jacob disease (CJD): a degenerative neurological disease.

Crop–livestock systems: farms that both crop and breed and grow livestock.

Crossbreeding: mating of individuals that are less closely related than the population average or a mating system in which two or more straight breeds are combined. It is generally regarded as between defined breeds.

Cryotherapy: treatment of a lesion by freezing of affected tissue.

Culled for age (CFA): a reject old animal that is past its economic life for particular conditions.

Cultivated pastures: an area of prepared land seeded with productive forage species for the grazing of livestock or hay making.

Customers: entities that buy the output of a business. Targeting a market involves identifying potential customers who will pay the business for attributes the business can control in a product. This may be the last customer (i.e. the final consumer) or other entities in the value chain. For farm output, it is often the first buyer in the value chain.

Cyanosis: blue or purple colouration of the skin or mucous membranes due to poor oxygenation of the surface blood vessels.

Dairy beef: beef produced from cattle breeds that are more usually associated with the dairy industry, or their crossbreeds. In Australia, dairy beef is largely grown opportunistically by utilising male calves, which are reared and grown to supply specialised beef markets rather than being slaughtered as 'bobby calves'.

Debt servicing capacity: annual whole-farm net cash flow available to meet interest and loan repayments.

Decision analysis: a procedure for rigorously and methodically assessing the expected benefits and costs of a possible action. A way of ensuring that decision-makers make decisions that are consistent with their personal beliefs about the risks they face and their personal preferences for possible consequences of the decision.

Decision tree: a diagrammatic representation of the alternative and sequential actions of a risky decision problem.

Demand: the amount of a product or service that consumers wish to buy at a range of prices.

Depreciation: the loss in value of capital items as they get used and become older.

Desertification: soil degradation that occurs in drylands and that is triggered by drought, reduced vegetation cover, overgrazing or their interaction.

Deterministic: often taken to mean causal determinism, or cause-and-effect. It is the concept that events within a given paradigm are bound by causality in such a way that any state (of an object or event) is completely determined by prior states with no random effects.

Development budget: a budget of cash flows used to assess expected profitability and financial feasibility when planning major farm system changes that will take some time to reach full capacity.

Dieback: the widespread premature death or decline in the health of individual trees, woodland or forest, characterised by the progressive dying back of trees.

Diminishing marginal returns: the phenomenon that increases in variable inputs added to fixed inputs in a production process result in smaller and smaller increases in total output. The principle of diminishing returns indicates that variable input should be added to the production process so long as the extra return exceeds the extra cost; the maximum total profit is at the point where extra return equals extra cost.

Discounting: the process of adjusting the value of a benefit or cost to be received in the future to its equivalent value at the present time.

Discounting factor: the adjustment factor used to adjust future values to present values, given by the formula 1/(1 + r)^n, where 'r' is discount rate and 'n' is the number of the year in the future in which the benefit or cost occurs.

Discovery: the discovery phase of DNA markers occurs when an association between a DNA marker and an economically important trait is first identified in a population of cattle that has been accurately measured for the trait of interest. The Beef CRC undertakes its discovery phase in at least 1000 animals.

Driver: a pressure or influence on human behaviour.

Dry matter (DM): herbage mass, pasture biomass or pasture dry weight (synonyms).

Dry sheep equivalent (DSE or dse) (southern Australia): 1 DSE represents the consumption of 1 kg DM of pasture of average quality (~9 MJ ME), which is the energy required each day for a mature 50 kg wether or dry ewe to maintain bodyweight. A 350 kg beef yearling gaining 1 kg/day has a DSE rating of 10.4.

Duty of care: the obligation on an individual to adhere to a standard of reasonable care while performing acts that could foreseeably harm the environment or others.

Dyspnoea: difficult or uncomfortable breathing.

Dystocia: abnormal or difficult birth. It may occur in ~10–15% of first-calf heifers and 3–5% of mature cows.

Ecological footprint: the amount of productive land appropriated on average by a person or community for food, water, transport, housing, waste management and other purposes.

Economic efficiency: measured by percentage return on all the capital invested in a business.

Ecosystem: a biotic community (plants, animals and microbes, including humans) and its abiotic environment (atmosphere, soil, water etc.), which function together as an interacting system.

Ecosystem composition: the identity and number of organisms in an area.

Ecosystem function: the interactions between organisms, and between organisms and the abiotic environment in an area.

Ecosystem goods: products of ecosystems and renewable resources that are directly harvested by society (e.g. fresh water, food, fibre, fuelwood, biochemicals and genetic resources).

Ecosystem services: the benefits to humankind derived from the ecological functioning of the biosphere.

Ecosystem stewardship, resilience-based: a suite of approaches whose goal is to sustain social–ecological systems, based on reducing vulnerability and enhancing adaptive capacity, resilience and transformability. Its goals are to respond to and shape change in social–ecological systems in order to sustain the supply of and opportunities for use of ecosystem services by society.

Ecosystem structure: the physical attributes of an ecosystem.

Effective population size: the number of breeding individuals in an ideal population that would show the same amount of dispersion of allele or gene frequencies under random genetic drift or the same amount of inbreeding as the population under consideration.

Elasticity of demand: the responsiveness of the quantity of a product or service that people demand, to a change in price or a change in income. Price elasticity is measured as percentage change in quantity demanded, divided by percentage change in price. Income elasticity is measured as percentage change in quantity demanded, divided by percentage change in income.

Empirical: information gained by means of observation or experiments.

Empty bodyweight: liveweight of animal minus the weight of the digestive system contents; may also refer to animals that have been fasted for a few hours.

Endangered community: a biological community facing a very high risk of extinction in the near future.

Endangered species: a species facing a very high risk of extinction in the near future.

Endophyte: fungi living in a symbiotic relationship with plants.

Endotoxin: toxin contained within a bacterial cell that is released upon death of the cell.

Enterprise: the production of a particular commodity or group of related commodities. It is a general term, e.g. wheat, beef.

Environmental correlation: a correlation between two traits as a result of experiencing common environmental conditions.

Environmental legislation (Brazil): laws and regulations that impose rules regarding environmental stewardship. Depending on where a ranch is located, 20–80% of the area has to be kept untouched (this area is called *reserva legal*). Areas surrounding rivers, ponds, lakes and on tops of hills also have to be preserved.

Environmental stewardship: environmental management by private citizens for the public good.

Epigenetics: changes in gene expression caused by mechanisms other than changes in the underlying DNA sequence.

Epimysium: the outer connective tissue layer of muscle.

Equity: the value of assets minus liabilities. It is also known as net worth and is what the business owes the owners.

Equity percent: farm equity capital as a percentage of total farm capital (i.e. [assets minus liabilities/assets]*100/1).

Essential amino acid: one of nine amino acids that cannot be synthesised by cells in the human body.

Estimated breeding values (EBV): an estimate of the breeding value that an animal will pass on to its progeny. It is estimated using all available information from relatives and correlated traits. EBVs are increasingly including information from DNA or genomic tests.

Etiology: causes of or origin of.

European Union (EU): cattle destined for the EU market must be produced according to specific requirements and be accompanied by an EU Vendor Declaration.

Exporter Supply Chain Assurance System (ESCAS): a framework put in place by the Australian government that places responsibility on exporters to guarantee measurable animal welfare outcomes throughout the entire supply chain in overseas marketplaces, through to point of slaughter. Exporters seeking a permit must show that their supply chain meets World Organisation for Animal Health guidelines for animal welfare, enables animals to be traced, has adequate reporting and is independently audited.

Exsanguination: the act of cutting and draining the blood vessels in the neck or upper chest.

Externality: an effect of production or consumption that is not taken into account by the producer or consumer because it is not reflected in the prices they pay but which influences the well-being or costs of other producers or consumers.

Eye muscle area (EMA): a cross-sectional measure of the eye muscle of an animal.

'Fair deal' marketing strategy: the targeting of market segments that are mainly concerned with good value purchases, given adequate product quality in general terms. It is also called 'cost leadership'. The emphasis in the business and value chain has to be on driving costs down while keeping quality acceptable but not premium.

Farm benefit–cost analysis: the budgeting process of evaluating the benefits and the costs and the net benefits of an investment to change a farm system.

Farm business profit: defined as the sum of farm cash income and build-up in trading stocks, minus the sum of depreciation plus the imputed value of the labour provided by the operator or manager, partners and family.

Fast variable: variable that responds sensitively to daily, seasonal and interannual variation in exogenous or endogenous conditions.

Fat score: an expression of how fat an animal is.

Febrile: an animal with a fever.

Fed cattle (US): cattle that have completed the feedlot fattening phase with approximately 10 mm of 12th rib fat and that are typically 14–20 months of age.

Feed conversion ratio (FCR): weight of feed required per unit of weight gain, often expressed as kg of dry feed per kg of liveweight gain.

Feed demand calculator: a tool developed by the MLA to help livestock producers gain an appreciation of the pattern of feed supply and demand over a 12-month period, the location of feed gaps and the ways in which modifying the livestock enterprise might help to close those gaps.

Feedlot: a facility where cattle are confined and intensively fed a high-concentrate feed in the period before slaughter. Feedlots can produce cattle suitable for different (short- and long-fed) markets.

Feedlotting: the process of intensively fattening or feeding cattle using carefully managed rations. Cattle are typically housed in a confined area.

Feedyard (US): common industry term for a feedlot; location where cattle are concentrated and fed complete, grain-based diets for 100-240 days prior to slaughter.

Female cattle: classified as weaner heifers, maiden heifers or heifers, first lactation cows, mature cows and aged cows (see definitions elsewhere in Glossary for each category).

Finance budget: a budget showing the flows of cash in and out, in nominal dollars. It identifies borrowings that are needed and interest and principal repayments.

Finishing: growing cattle up to a marketable or desirable weight and fat score using differing feed sources, i.e. can be pasture- or grain-finished.

First lactation cows: females from their first calving to weaning of that calf.

Fisher quantity index: also known as the 'ideal' price, defined as the geometric mean of the Laspeyres and Paasche quantity indices.

Fixed capital: land, buildings, bores, irrigation equipment etc. that cannot easily be moved.

Fixed costs: costs that must be met and are not affected by the amount of output produced in a year. Also called overhead costs. They are unavoidable costs in the short to medium term.

Flight speed: the speed at which an animal leaves a crush over a defined distance.

Follicle-stimulating hormone (FSH): a hormone secreted by the anterior lobe of the pituitary in the brain in response to GnRH. FSH promotes follicular development in the female and testicular cell function in the male.

Fomite: any inanimate object or substance capable of carrying infectious organisms.

Food-borne diseases: a range of diseases resulting from the consumption of contaminated food.

Foot and mouth disease (FMD): *Aphthae epizooticae* is an infectious and sometimes fatal viral disease that affects cloven-hoofed animals. The virus causes a high fever for two to three days, followed by blisters inside the mouth and on the feet that may rupture and cause lameness.

Forbs: broad-leaved herbaceous plants other than grasses and sedges (which are collectively known as monocots). In contrast, herbs are non-woody vascular plants, i.e. forbs, monocots and ferns.

Fragmentation: the process of the loss and modification of native vegetation and wildlife habitat in an area due to human activity.

Futures: quantities of a commodity of defined quality for delivery at an agreed future date.

Gearing: the ratio of debt to equity. It has implications for debt servicing ability and rate of growth of equity. Also called 'leverage'.

Genetic correlation: a correlation between two traits as a result of the genes they share that affect both traits.

Genomic selection: selection decisions based on genomic information that includes many SNP genotypes and that have already been correlated with phenotypes.

Genotype: the genetic makeup of an individual, generally described as a series of nucleotides at multiple locations throughout the genome (DNA); also sometimes used to indicate the breed composition of an animal.

Germplasm: collection of genetic material usually representing known diversity for a species.

Gluconeogenesis: synthesis of glucose from non-carbohydrates, some amino acids and glycerol.

Glycogen: branched chain polysaccharide made up of glucose units; acts as a storage substance in vertebrate liver and muscle.

Glycolysis: anaerobic breakdown of glucose to pyruvate in cells, with the production of ATP.

Gompertz function: a sigmoid function. It is a type of mathematical model for a time series, where growth is slowest at the start and end of a time period. The right-hand or future-value asymptote of the function is approached much more gradually by the curve than the left-hand or lower-value asymptote.

Gonadotrophin releasing hormone (GnRH): a protein released from neurones in the hypothalamus in the brain that cause the release of FSH and LH from the anterior lobe of the pituitary.

Great acceleration: the explosion of the human enterprise in terms of population and economic activities after the Second World War.

Greenhouse gas (GHG): an atmospheric gas that absorbs and emits radiation within the thermal infrared range. The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone.

Grid: a schedule of rates paid for particular carcass characteristics such as weight and fat cover. It is typically used in direct or over-the-hook transactions.

Gross margin (GM): gross income minus variable costs. It can be whole-farm gross margin, as in a whole-farm budget, or an activity gross margin.

Growth: increase in net worth (wealth) over time. It is measured as change in equity, or net farm income minus tax and consumption above operator's allowance.

Growth phase: phase of an adaptive cycle during which environmental resources are incorporated into living organisms and policies become regularised.

Growth rate: the rate of growth of an animal. It is usually expressed in kg of liveweight per day.

Habitat: the biophysical description of the area in which an organism can reside and survive.

Habitat connectivity: the link or linkages between large areas of habitat by more tenuous corridors or 'stepping stones' of habitat.

Habitat restoration: the branch of ecology that focuses on the reconstruction, repair and rehabilitation of degraded areas of habitat.

Haemangiosarcoma: tumour of blood vessel cell origin.

Hardiness: ability of a breed to deal with harsh environment conditions, such as poor forage quality and low availability, incidence of parasites, hot and humid weather.

Hayed-off: pastures that have senesced or moved from active growth to death or dormancy.

Hazard analysis and critical control points (HACCP): a systematic preventive approach to food safety and allergenic, chemical and biological hazards in production processes that can cause the finished product to be unsafe; designs measurements to reduce these risks to a safe level.

Hedging: insuring against a loss on holding stocks of a commodity due to a price change during the period of ownership.

Heifer: see maiden heifer.

Hepatic vagotomy: sectioning of the vagus nerve serving the liver, such that signals from the liver cannot reach the brain.

Herbage mass: the total amount of forage available, measured in kg of dry matter per hectare (kg DM/ha), including grasses, forbs and legumes. Also known as pasture biomass, pasture dry weight.

Heritability: the proportion of superiority in the parents that is expressed in the progeny.

Heterosis: from the word hetero-zygosis; defined as the additional performance of a hybrid over the mean of the parent breeds.

High conservation value: an elevated ranking owing to the native biodiversity present.

High-rainfall zone (southern Australia): areas receiving 550 mm or more average annual rainfall.

Hormone implants: hormones that are administered to cattle to enhance growth rates or deliver a modified fertility outcome.

Hot Standard Carcass Weight (HSCW): the fundamental unit of over-the-hooks selling; the weight, within two hours of slaughter, of a carcass with standard trim (all fats out).

Hybrid vigour: the superiority in performance of crossbred animals compared to the average of their parents. Also known as heterosis.

Hyperaesthesia: an abnormal increase in the sensitivity of the senses.

Hypocalcaemia: low levels of calcium in the blood and plasma.

Hypocuprosis: a condition characterised by low levels of copper in the blood and plasma due to low availability of copper in the diet or interference with copper uptake due to high levels of sulphur or molybdenum in the diet.

Hypoglycaemia: abnormally low levels of glucose in the blood.

Hypomagnesaemia: low levels of magnesium in the blood and plasma.

Hypophagia: reduced voluntary feed intake, below what is expected from dietary analysis.

Hypopyon: pus in the (anterior chamber of the) eye.

Hypoxia: regional or systemic deprivation of oxygen supply.

Iatrogenic: response to medical or surgical treatment, induced by the treatment itself. It is usually associated with adverse effects resulting from medical treatment or advice.

Inbreeding: mating of individuals that are more closely related than the population average.

Inbreeding coefficient: the probability that a gene present in one parent is also present in the other parent and has been derived from a common ancestor.

Income elasticity: the responsiveness of demand to changes in income.

Inflation: an increase in the supply of money in relation to the supply of goods and services available and, in consequence, a decline in the purchasing power or value of currency.

Innovation: a novel and/or new approach.

Interdigital: between the claws.

Interest: the annual sum that a lender charges someone who borrows funds. Expressed as a percentage of the sum borrowed, e.g. 10% interest/year on $100 000 borrowed.

Interest-only loan: a loan where the borrowed capital is not intended to be repaid on a regular and gradual basis over the life of the loan and instead annual interest is paid on the full amount of the borrowed capital for the life of the loan.

Intermediate activity: the production of a commodity that is not sold directly but becomes an input for other activities of the farm, e.g. stubble for grazing.

Internal rate of return: the discount rate at which the present value of future benefits from a project equals the present value of total costs of the project.

Intramuscular fat (IMF): fat laid down within rather than between muscles.

Intrapalpebral: within the eyelid.

In utero: in the uterus.

Invasive species: a species occurring, as a result of human activities, beyond its accepted normal distribution and which threatens valued environmental, agricultural or other social resources due to the damage it causes.

Investment appraisal: an evaluation of the profitability and financial feasibility of a potential investment.

Ischiorectal fossa: hollow between the pin bone and the tail butt.

Joining (southern Australia) or **mating (northern Australia):** cows and bulls put in the same paddock to give them an opportunity for mating.

Key performance indicators (KPI): quantifiable measurements that reflect the success factors of an organisation. They should reflect the goals of the organisation.

Landcare: any policy, strategy or practice furthering sustainable land management, or the grass-roots movement among farmers in rural Australia to repair and improve farmland condition, funded principally by the federal government, philanthropy and farmers themselves.

Land condition: the state of a terrestrial ecosystem in relation to its ability to deliver desired ecosystem goods and services.

Land degradation: deterioration of land to a less desirable state as a result of failure to actively adapt or transform, resulting in reduced ecosystem goods and services.

Leukopaenia: reduction in leukocyte (white blood cell) count.

Level: a unit of analysis located at a particular position on a scale.

Life-support system: supporting ecosystem services that give rise to the provisioning, regulating and cultural ecosystem services desired by society.

Linear programming: a mathematical, computer-based, farm-planning technique that determines the combination of activities that maximises total gross margin or profit, or minimises costs. There are usually a range of alternative solutions (farm plans) that produce a total gross margin or profit very close to the optimum, and the practical decision rule is not so much what you do as how you do it.

Liquidity: cash or near-cash reserves**.** Relates to the ability of a business to service debt.

Live export cattle: cattle transported live to an overseas market, usually by sea.

Livestock feed budget: a budget comparing current and predicted feed requirements of livestock with the available feed and the expected supply.

Livestock gross income: the value of livestock production in the form of animals and produce, adjusted for inventory changes.

Livestock trading schedule: a budget used to estimate the annual contribution to gross income from the trading of animals by sales and purchases, births and deaths, and changes in the numbers and value of livestock on hand, from opening number and value to closing number and value. It captures the effects of animal depreciation and appreciation, as well as natural increase.

Long-fed: cattle that are fed a finishing ration for 150–350 days.

Low-stress stock handling: a method for handling livestock to minimise stress.

Luteinising hormone (LH): hormone secreted by the anterior lobe of the pituitary in the brain that causes ovulation and subsequent development and maintenance of the *corpus luteum* in the ovary. In the male, LH causes the Leydig cells to produce testosterone.

Machinery replacement allowance: sum deducted from net cash flow each year so that funds are available to replace capital items when they are worn out.

Maiden heifer or **heifer:** heifers still to be joined for the first time. These could be as yearlings (from about 12–15 months onwards) or as two-year-olds.

Marginal: economists' word for extra or added. The principle of marginality is the profit-maximising level of operation where the marginal revenue from production equals the marginal cost of production.

Marginal cost: the extra cost added to total cost from using an extra unit of a variable input, or the extra cost incurred in growing or selling an additional unit of product.

Marginal lands: relatively unproductive terrestrial ecosystems in relation to a specified agricultural enterprise.

Marginal product: the change in output arising from using an extra unit of a variable input.

Marginal revenue: the extra net income obtained from selling one additional unit of product.

Marginal value product: the value of an extra unit of output; the marginal physical product of a unit of output times the price per unit of the product.

Market niches: market segments that, while small and therefore unattractive to larger business competitors, are attractive possible targets for a business, due to the match of business capabilities and niche preferences. Niches are commonly targeted with convenience strategies because the attributes of interest to them are other than price.

Market segments: groups of consumers with similar preferences. The number of segments identified in an entire market depends on the fineness with which preferences are specified: the finer the preference criteria, the more the segments.

Market specifications: several attributes recorded and explicitly sought for live animals and carcasses are collectively referred to as market specifications. They vary with consumer demand, market type and destination.

Market targeting: the selection of customers on whom to focus output. This requires an understanding of business capabilities and customer segment preferences at the various feasible market levels within the value chain, which may profitably be targeted. The selection of target markets is intrinsically strategic. Failure to consider what customers seek in output will lead to lower sales revenue for output.

Marketing: all decisions made by an entity that determine the characteristics of the output (the marketing mix) presented to potential customers.

Marketing channel: the path between a specific organisation and its customers; one segment only of a marketing system.

Marketing margin: the difference between the purchase price and resale price of a product between two levels in a marketing chain. It indicates the cost of adding services to products.

Marketing mix: the entire set of characteristics of a product that a producer presents to a potential customer; often defined as being composed of product, price, place and promotion (the four Ps).

Marketing system: the entire system composed of entities contributing to the production of a category of product. Also, in agricultural product contexts, called an agribusiness system**.**

Mature cows: cows from the weaning of their first calf until leaving the herd.

Mature weight: the weight of a five-year-old cow in average condition (condition score 3).

Meat and Livestock Australia (MLA): a company owned by Australian livestock producers with responsibility for red meat industry R&D as well as the promotion and marketing of red meat within Australia and internationally.

Meat Standards Australia (MSA): a carcass grading system designed to guarantee eating quality of specific cuts of meat and specific cooking methods. It is managed by Meat and Livestock Australia.

Mechanoreceptors: specialised nerve cells in the walls of the gastrointestinal tract, which respond to distension of the gut due to the presence of ingesta.

Meristem: a growing point of a (grass) plant.

Metabolisable energy (ME): energy from food available for metabolic processes after losses in faeces, urine and methane.

Methanogenic microbes: rumen microorganisms that produce methane (CH_4), a greenhouse gas.

Micrometer (micron): a unit of distance equal to one millionth of a metre.

Millennium development goals: eight international targets established following the Millennium Summit of the UN in 2000 and the adoption of the UN Millennium Declaration. All 189 UN member states and at least 23 international organisations agreed to achieve these goals by the year 2015. The goals are**:** 1. eradicating extreme poverty and hunger; 2. achieving universal primary education; 3. promoting gender equality and empowering women; 4. teducing child mortality rates; 5. improving maternal health; 6. combating HIV/AIDS, malaria and other diseases; 7. ensuring environmental sustainability; 8. developing a global partnership for development.

Mishima Island cattle (Mishima gyu): native cattle, not strictly Wagyu. Similar characteristics to the Japanese Black founder cattle. Mishima Island cattle had never been influenced by foreign breeds and were designated as a protected species in 1928. The breed is named after tiny Mishima Island in the Sea of Japan, 40 km north-west of Yamaguchi Prefecture. Its estimated population was only 14 males and 85 females in 2006. The Mishima Island cattle have a brownish-black coat and skin. They produce excellent meat of high marbling quality.

Mixed farming systems: farming operations with poly-focal production focuses.

MJ/ME kg DM: megajoules (energy) per kg of dry matter.

Monopoly: a market in which there is only one seller of a product or service.

Morbidity: the rate of incidence of a disease or ill health.

Most Favoured Nations (**MFN**)**:** used in trade agreements, including WTO agreements, to establish reciprocal treatment between trading partners.

Multiplier: seedstock or stud herd that rarely sells bulls to other studs, but buys bulls from other studs and breeds bulls for commercial producers that sell steers and heifers. These studs play an important role in industry but do not lead to genetic progress.

Myonecrosis: death of muscle tissue.

National Livestock Identification Scheme (NLIS): The National Livestock Identification System is Australia's system for identification and traceability of livestock. It was introduced in 1999 to enhance Australia's ability to track cattle during disease and food incidents. Since then it has expanded to enable not only cattle, but also sheep and goats to be traced from property of birth to slaughter, hence increasing biosecurity, meat safety, product integrity and market access.

Native pasture species: forage plants considered to be present at the time of non-indigenous settlement.

Natural resource management: decision-making and interventions in relation to biophysical assets such as atmosphere, water, soil, vegetation and fauna.

Naturalised pasture species: exotic or introduced plants that have not been deliberately sown but are well adapted to the environment where they occur and spread naturally.

Necrosis: unprogrammed death of cells or tissues.

Nellore: *Bos indicus* breed, originally from India. Some animals were imported into Brazil during the 1960s and 1970s. The breed represents 80% of the Brazilian beef cattle herd.

Neophilia: love of, or enthusiasm for, what is new or novel; stimulation of voluntary feed intake as a result of the presentation of novel feedstuffs.

Neophobia: fear of new things or experiences; in relation to novel feedstuffs or novel feeding situations, which results in a reduction in voluntary feed intake.

Net cash flow: the difference between the money received and the money spent in any one period (e.g. week, month or year).

Net farm income: operating profit minus interest; the return on the owner's capital. Also called net profit.

Net present value (NPV): the difference between the present value of all benefits and present value of all costs of an investment, with the present values of benefits and costs calculated using a particular discount rate.

Net worth: the value of total assets minus the value of total liabilities (equity).

Neutral detergent fibre (NDF): the fibrous component remaining after treatment with a neutral detergent; comprises a varying combination of lignin, hemicelluloses and cellulose.

Neutropaenia: reduction in neutrophil (pus cells) count.

No-kill cropping: the sowing of a crop into an established pasture using a no-till implement, causing negligible damage to the pasture.

Nominal terms: dollar values or interest rates that include an inflation component.

North American Free Trade Agreement (NAFTA): treaty approved in 1994 that allows free trade among Canada, Mexico and the USA duty-free.

Northern region (Australia): Northern Territory, Queensland and northern pastoral zone of Western Australia.

Oedema: fluid accumulation in tissues or body cavities.

Oestrous synchronisation: the use of hormones to manipulate the female reproductive cycle so that they ovulate and can be inseminated within a short period.

Old-growth tree: a tree that is overmature and not increasing in biomass, having achieved net carbon balance, i.e. the rate of accumulation of carbon in terms of photosynthesis is equal to the rate of loss of carbon through respiration, decay and disturbance.

Oligopoly: market in which there are only a few sellers of a product or service so that each will be affected substantially by a change in policy on the part of another.

Operating costs: variable costs plus overhead costs.

Operating profit: defined as gross income minus variable and fixed (overhead) costs; the return on all the capital invested.

Opisthototonos: backward arching of the neck and back.

Opportunity cost: the amount of net benefit that is given up by choosing one action rather than some alternative action.

Orexigenic: causing appetite enhancement.

Organic beef production: a form of farming that emphasises the soil–plant–animal complex, and utilises manures and composts free of synthetic chemicals. Organic food can be produced and marketed after accreditation standards have been met for three consecutive years, and farms certified as organic can legally label product as organic after being accredited.

Osmolality: the osmotic concentration of a solution, which can be measured by osmotic pressure.

Osmoreceptors: specialised nerve cells in the gut wall that respond to changes in the osmolarity of the ingesta.

Osteochondrosis desiccans (OCD): a disease causing inflammation and damage mainly to the stifle, carpus, tarsus, carpus and shoulder joints. The disease is more prevalent in animals fed diets that induce high growth rates for sustained periods.

Overhead (fixed) costs: costs that do not vary as the level of production or mixture of activities changes. They are unavoidable costs in the short to medium term.

Over-the-hooks (OTH): a term which describes cattle being sold direct to the processor with payment based on objective carcass measurements post- slaughter.

Packer/packing plant (US): industry term for buyer of slaughter animals/location of animal slaughter and processing.

Pancytopaenia: reduction in red and white blood cell and platelet count.

Papilloma: wart.

Parameter: any factor that has an important effect on profit, e.g. yield, price, hectarage, direct cost.

Parametric budget: a planning technique that takes varying prices and yields into account.

Parenteral: provision of nutrition or medication via a route other than the mouth.

Pareto improvement: given an initial allocation of goods among a set of individuals, a change to a different allocation that makes at least one individual better off without making anyone else worse off.

Partial budget: a budget drawn up to estimate the effect on profit of a proposed change affecting only part of the farm. It is used to estimate the additional return on extra capital invested.

Pasture cropping: the drilling of a crop into an established but seasonally dormant or chemically suppressed pasture using minimum-till equipment.

Path dependence: effects of historical legacies on the future trajectory of a system; more narrowly, the coevolution of institutions and social–ecological conditions in a particular historical context.

Pathogen: a microorganism that can cause disease.

Payoff matrix: a table showing the probabilities and outcomes of different acts and states of nature.

Perennial grasses: plants of the family Poaceae with the capacity to survive and produce forage for more than one year.

Peri-urban: landscape characterised by both urban and rural social and economic activities.

Pestivirus: a disease in cattle that causes abortion, ill-thrift in young animals, diarrhoea and respiratory disease. Transmission is by direct contact with a carrier animal. Also known as bovine viral diarrhoea virus (BVDV).

Phagocytosed: the ingestion of bacteria by cells of the immune system.

Phenotype: the measurable characteristic of an individual, which is a function of its genotype and environmental factors.

Polioencephalomalacia: a neurological disorder characterised by incoordination, 'star-gazing', convulsions and the presence of characteristic lesions in the brain associated with low levels of available thiamine or excess levels of sulphur in the diet.

Polyphenolics: a class of compounds containing polymers of phenol groups; in animal nutrition, largely represented by the tannins.

P8 site: an abbreviation for 'Position 8' for fat assessment on cattle. The P8 site is on the rump, forward of the tail head above the short ribs.

Positive fat: cattle that demonstrate body fat above the breed average.

Pregnancy-tested in calf (PTIC): a cow that has been pregnancy-tested and is in calf.

Principal: the amount of capital borrowed when a loan is taken out. Principal repayments are the amounts of capital repaid to settle a debt.

Principle of increasing risk: the more highly geared the business, the more rapidly equity grows when things go well. However, equity declines at an even faster rate when things go badly.

Prions: proteinaceous infectious particles lacking nucleic acid.

Product value: the judgement that final consumers make on the usefulness of an available product. It is based on the attributes it offers relative to their preferences, and its price relative to the price of alternative products with similar attributes.

Production function: the relationship between the level of inputs and the level of output for a production process. Also called a response function.

Production-possibility frontier (PPF): outputs curve at the points of maximum production efficiency where no more output can be achieved from the given inputs.

Proteolysis: degradation of proteins into smaller subunits that occurs with ageing, but also in turnover of living muscle.

Pyrexia: fever.

Quantitative trait loci (QTL): stretches of DNA containing or linked to the genes that underlie a quantitative trait.

Rainfall to pasture growth outlook: the rainfall to pasture growth outlook tool developed by MLA that presents the actual rainfall and indices of soil moisture and pasture growth for the past nine months and an outlook for the next three months.

Real terms: dollar values or interest rates that have no inflation component.

Recumbency: lying down.

Regime shift: abrupt large-scale transition to a new state or stability domain characterised by very different structure and feedbacks.

Release phase: phase of an adaptive cycle that radically and rapidly reduces the structural complexity of a system.

Remnant (vegetation): native vegetation that remains after an area has been otherwise cleared.

Renewal phase: phase of an adaptive cycle in which the system reorganises through the development of stabilising feedbacks that tend to sustain properties over time.

Renminbi (Rmb): the Chinese currency. Value ranged from Rmb8.3 to Rmb6.3 to the US$1 between 2000 and 2012.

Reorganisation: the redevelopment of system structure as a result of stabilising feedbacks among system components.

Residual feed intake (RFI): effectively partitioning feed intake into two components: 1) the feed intake expected for the given level of production, and 2) a residual portion. The residual portion (RFI) can be used to identify animals that deviate from their expected level of feed intake; they can be classified as high-efficiency (negative residual intake) or low-efficiency (positive residual intake).

Residual herbage mass: the amount of herbage mass, expressed in kg of dry matter per hectare (kg DM/ha), remaining in a paddock after a graze event.

Resilience: capacity of a social–ecological system to absorb a spectrum of shocks or perturbations and to sustain and develop its fundamental function, structure, identity and feedbacks as a result of recovery or reorganisation in a new context.

Return on total assets: operating profit expressed as a percentage of the value of total farm assets.

Return on total capital (ROTC): the annual operating profit expressed as a percentage of the total capital invested in the business over the year. Total capital can be capital at the start or end, or an average of the start and end capital value. Percentage return on total capital is a measure of economic efficiency.

Rigor: when individual muscle fibres have been depleted of ATP and actomyosin has formed.

Rigor mortis: when muscles stiffen after all muscle fibres enter rigor.

Rinderpest: a highly contagious viral disease affecting cattle.

Risk: a situation with uncertain outcomes, but where some probabilities can be formed about the outcomes. In contrast to uncertainty, where no probabilities can be formed about uncertain events happening.

Risk premium: an amount that a person requires above a risk-free return before being willing to accept a risk.

Robert Bakewell: A pioneer stock breeder of sheep and cattle in England in the second half of the 18th century.

Rotational grazing: the practice of rotating livestock through a series of paddocks.

Rumen degradable protein (RDP): dietary protein that is degraded by microbial enzymes into non-protein nitrogen such as ammonia.

Ruminitis: inflammation of the ruminal epithelium.

Rupiah (Rp): the Indonesian currency. Value ranged from Rp7200 to Rp11 860 to the US$1 between 2000 and 2012.

Saleyards: locations where local producers can sell cattle on a regular basis. Many rural towns have saleyards.

Sanga: adapted *Bos taurus* breeds that evolved in southern Africa independent of the European *Bos taurus*. They retain the productive attributes of the European *Bos taurus* but have resistance closer to that of the *Bos indicus*.

Sarcomere length: distance between Z-disks in skeletal muscle, usually measured post-rigor.

Scale: a spatial, temporal, quantitative or analytical dimension (e.g. space, time, jurisdictions, institutions, management, networks, knowledge) used to measure and study phenomena.

Scenario analysis: a way of imagining a set of combined circumstances in the future and the implications for important decision criteria, e.g. profit, growth, financial feasibility and risk.

Scour: diarrhoea caused by a pathogen or nutritional imbalance.

Seedstock: cattle bred for breeding other cattle rather than for production of beef *per se*. These may or may not be studs that are registered with a breed society.

Seedstock operation: cow–calf operation that typically has cattle registered in respective breed society/association herd books with the primary goal of selling breeding animals to other cow–calf operations.

Sensitivity testing: checking the effect on a planned outcome of a change in one of the factors (parameters, coefficients) that affects that outcome.

Sex-limited: traits that are expressed in only one sex but are affected by genes from both parents. The most common example is milk yield.

Shortening: a process that occurs when pre-rigor muscle is cooled below 10°C when the pH is still above 6.0. Also occurs as muscles enter rigor at high temperatures (rigor shortening).

Short-fed: cattle that are fed a finishing ration for 70–150 days.

Sidewinder bull: a teaser animal used for heat detection. It is capable of mounting but not serving females because the penis has been surgically relocated from the midline to the flank so that it protrudes at right angles to the body.

Single nucleotide polymorphism (SNP): a DNA sequence variation occurring in a single base nucleotide (A, T, C or G) in the genome.

Slow variable: variables that strongly influence social–ecological systems but remain relatively constant over years to decades.

Social–ecological system: system with interacting and interdependent physical, biological and social components, emphasising the 'humans-in-nature' perspective.

Social facilitation: stimulation of voluntary feed intake induced by the presence of other cattle consuming feed.

Solvent: business condition where assets exceed debts.

Special Administrative Region (SAR): regions or territories that fall within the sovereignty of the People's Republic of China but which do not form part of mainland China. In 2013 there were two SARs, namely the Hong Kong SAR and the Macau SAR, former British and Portuguese dependencies, returned to China in 1997 and 1999 pursuant to the Sino-British Joint Declaration of 1984 and the Sino-Portuguese Joint Declaration of 1987, respectively.

Spot price: the price for a product available for immediate delivery.

Stabilising (negative) feedback: feedback that tends to reduce fluctuations in process rates, if extreme, it can induce chaotic fluctuations. A stabilising feedback occurs when two interacting components cause one another to change in opposing directions. Also known as negative feedback.

Starter ration: a ration fed when introducing livestock to a new feedstuff. Starter rations assist the rumen in adjusting to new feed stuffs.

Stochastic: behaviour is non-deterministic and can be thought of as a sequence of random variables. Any system or process that can be analysed using probability theory is stochastic.

Stock density: the number of dry sheep equivalents grazing an allocated area or paddock on any day.

Stock equivalents: units used in livestock feed budgeting whereby the energy needs of different categories of livestock are expressed in terms of one type of livestock, e.g. dry sheep equivalent in southern Australia.

Stocker cattle (US): cattle that are light weight such as 400–600lb (181–272kg) and young (four to nine months old) that are run on forage for three to six months prior to feedlot entry.

Stocking rate: the livestock numbers carried on a specified area of land, usually over a 12-month period. The number of livestock can be expressed as dry sheep equivalents, adult equivalents or stock equivalents, depending on location.

Stocking rate calculator: the calculator developed by MLA that is designed to determine the number of cattle or sheep that should be put into a paddock, based on its carrying capacity.

Strategic management: decisions about the way a business pursues its objectives that involve significant and enduring commitment of resources. Choice of target markets is one such decision.

Strategic marketing: the strategic marketing choice each beef producer has available, determined by the control they have over the characteristics of their output, especially quantity and quality, and the entry points to the value chain. Entry points are determined by live animal or carcass characteristics, and the market specifications outlined by specific markets.

Subacute ruminal acidosis: a chronic condition characterised by periods in which the pH of the ruminal fluid is 5.0–5.5, due to high levels of volatile fatty acids.

Subjective probability: the strength of belief an individual holds about the chance of a particular event occurring.

Substitution: the giving up of one enterprise or activity or input, for another enterprise or activity or input.

Supplementary feeding: the practice of supplying any of the constituent nutrients of an animal ration to livestock.

Supply: the amounts of a product or service that will be offered for sale at a range of prices.

Sustainability: use of the environment and resources to meet the needs of the present without compromising the ability of future generations to meet their own needs; the maintenance of the productive base (total capital) over time.

Sustainable development: activity that seeks to improve human well-being, while at the same time sustaining the natural resource base and material opportunities on which future generations depend.

Sustainable management: decision-making and interventions that sustain the functional properties of social–ecological systems that are important to society.

Tactical management: adjustments of business activity, within the constraints imposed by strategy, to relevant short-term changes in the management environment.

Target marketing: subcategories within market areas targeting more specialised markets, e.g. long-fed, highly marbled cattle, and enterprise options including a breeding or a trading focus. The selection of target markets is intrinsically strategic, and outputs that satisfy customer requirements will lead to higher sales revenue.

Teaser: cattle, usually male, used to detect heat. They are either sterilised or incapable of service and used in conjunction with mechanical heat detection aids such as chinball harnesses.

Technical efficiency: a ratio of the quantity of physical output to quantity of physical input. It does not indicate profitability or economic efficiency.

Term loan: a loan that is to be repaid in equal annual instalments of principal, with interest charged on the reducing outstanding balance of the loan.

Terms of trade: the quantity of imports that can be purchased through the sale of a fixed quantity of exports, expressed as a single ratio of the relative prices.

Terminal progeny: the final progeny delivered through a crossbreeding program.

Terminal sire: bull used over cows where all the progeny are sold for meat production rather than kept for ongoing breeding.

Tetany: involuntary contraction of muscles.

Thrombocytopaenia: reduction in thrombocyte (blood platelets) count.

Tick line (Australia): a defined boundary of the cattle tick-infested areas of Queensland, Northern Territory and Western Australia (at an approximate latitude of 19.25°S).

Total factor productivity (TFP): a variable that accounts for effects in total output not caused by traditionally measured inputs. TFP cannot be measured directly. Instead it is a residual, which accounts for effects in total output not caused by capital and labour inputs. If all inputs are accounted for, then TFP can be taken as a measure of an industry's long-term technological change or technological dynamism, including knowledge of workers (human capital). Also called multi-factor productivity.

Trace element: a chemical element present only in minute amounts in a particular sample or environment.

Trading: the practice of buying and on-selling livestock.

Trait: distinguishing feature or characteristic usually reserved for the biological factors in a breeding objective. It can be improved genetically, e.g. growth rate, fertility, carcass or meat quality.

Trochars: large sharp-pointed cannula.

Trueness to type: an expression of the tendency of the progeny within a herd to reflect the traits of the herd.

Undegraded dietary protein (UDP): dietary protein which is not degraded in the rumen but is available for digestion post-ruminally.

Urolithiasis: blockage of the urinary system (commonly the urethra in male animals) by concretions of mineral salts, often calcium oxalate.

Uroliths: abnormal concretion usually comprised of mineral salts, in the urinary tract.

Utilisation: the percentage of pasture growth consumed by livestock within a defined period, usually 12 months.

Value chain: enterprises acting in concert to improve the economies of specific activities. The relationship may include alliances to vertically or horizontally integrate individuals across the same or different sector(s) of the beef industry. Also called supply chain.

Variable costs: costs that change directly according to the amount of output of the activity, e.g. fuel, seed. Also known as direct costs.

Vegetation composition: the identity and number of plants in an area.

Vegetation condition: the value of a given vegetation state to deliver a specified ecosystem good or service, e.g. native biodiversity conservation.

Vertical integration: the extent to which a value chain, or part of one, is controlled by a single entity to enhance its efficiency and its focus on consumer preferences, where the consumer is that targeted by the integrator. Supermarkets integrate backwards into the value chain for beef for major market segment customers; some beef producers integrate forwards to supply niches.

Viraemic: virus circulating in the blood stream.

Wagyu (Japan): four cattle breeds of Japanese Black, Japanese Brown-Kumamoto and -Kochi, Japanese Shorthorn and Japanese Polled. These four breeds were crossed with foreign breeds for genetic improvement of the indigenous breeds in the Meiji Era.

Wagyu brand (Japan): the brand Wagyu is a restricted terminology that refers to breeds or strains that meet high beef quality standards, feeding and rearing period (e.g. rice straw or corn-fed, 28–32 months), shipping weights etc. The restriction standards are defined by their promoting organisations (Agricultural Cooperative Associations, business enterprises and stock farms, etc.) within the guidelines of the Japan Livestock Industry Association (JLIA; http: //cali.lin.go.jp). There are about 100 Wagyu brands, e.g. Kobe beef, Matsuzaka beef, Yonezawa beef, Ohmi beef and Maesawa beef. Some regional brands of Wagyu are available to consumers only within small restricted areas because of the limited number of beef producers.

Water use efficiency (WUE): pasture grown per mm of rainfall within a defined period, seasonally or annually.

Weaner: calf at time it is separated from the cow and no longer able to suckle. Weaners can range in age from two to 10 months, but most commonly are around six to seven months.

Weaner heifers: females from weaning until about 12 months of age.

Weaning: the permanent separation of calves from their mothers.

Weaning rate: the percentage of cows in a herd that have weaned a live calf.

Wet markets: traditional places especially in Asia where stallholders sell fresh food. They dominate retail in developing Asia but are changing with increasing infrastructure, refrigeration, monitoring and greater range of consumer items.

Whole-farm approach: a farm management economic method. Understanding and analysing the farm system: the human, technical, economic, financial, risk, institutional elements, as a whole system.

Whole-farm cash budget: budget showing the expected flows of cash in and out of the business for the coming year.

Whole-farm planning: planning for the whole farm, as distinct from partial budget planning.

Whole-farm profit budget: budget showing the expected outcomes of a farm plan, in terms of the entire farm's profitability for the coming year.

Wicked problem: a challenge that is so complex that each attempted solution creates new conundrums for other segments of society or other times and places.

Working capital: capital needed for the day-to-day operation of a farm. It is usually funded by relatively short-term borrowings related to the length of the production cycle, e.g. by bank overdraft facility or bank bills.

Yard-weaning: the practice of weaning cattle within a confined environment (yards).

This page intentionally left blank

Abbreviations

AACo	Australian Agricultural Company
AB	Artifical breeding
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABIEC	Associação Brasileiras das Indústrias Exportadoras de Carne Bovina
ACIAR	Australian Centre for International Agricultural Research
ACV	Australian Cattle Veterninarians
ADB	Asian Development Bank
ADG	Average daily gain
AE	Adult equivalents
AHLU	Accumulated heat load units
AI	Artificial insemination
ALFA	Australian Lot feeders Association
AM	curly calf syndrome (arthrogryposis multiplex)
AQIS	Australian Quarantine Inspection Service
ARGT	Annual ryegrass toxicity
ASEAN	Association of South East Asian Nations
AV	Artificial vagina
BBSE	Bull breeding soundness examination
BCS	Body Condition Score
BCS2	Beef colour standards
BEF	Bovine ephemeral fever
BFR	Bull:female ratios
BFS	Beef fat standards
BIF	Beef Improvement Federation
BJD	Bovine Johne's disease
BMS	Beef Marbling Score number
BOD	biological oxygen demand
BPS	Indonesian Central Bureau of Statistics
BRD	Bovine respiratory disease
BRSL	Brazilian Roundtable on Sustainable Livestock
BSE	Bovine spongiform encephalopathy
BTA	bos taurus autosome
BTEC	Brucellosis and tuberculosis eradication
BVC	bovine venereal campylobacteriosis or vibriosis
BVDV	Bovine virus diarrhoea virus
CAAB	Certified Australian Angus Beef
CAP	Common Agricultural Policy
CCN	Cerebrocortical necrosis
CHO	Carbohydrate
CIDR	Controlled internal drug releasing devices
CIE	Centre for International Economics
CL	Corpus luteum
CMA	Catchment Management Authorities
CMW	Critical mating weight
CRC	Cooperative Research Centre
DCAD	dietary cation anion difference
DFD	Dark, firm and dry
DGLAHS	Director General of Livestock and Animal Health Services
DM	Dry matter
DMI	Dry matter intake
DOF	Days on feed
DOT	Dropped ovary technique
DSE	Dry sheep equivalent
EBIT	Earnings before interest and tax
EBV	Estimated breeding values
EC	Exceptional circumstances
EE	Electroejaculation
EEG	Electroencephalography
EEM	Early embryonic mortality
EMA	Eye muscle area
EPD	Expected prgoeny differences
ESCAS	Exporter supply chain assurance scheme
ETEC	Enterotoxigenic E. coli K99
EU	European Union
EUCAS	European Union Cattle Accreditation Scheme
F1	First cross
FAQ	Fair average quality
FCE	Feed conversion efficiency
FCR	Feed conversion ratio
FEC	Faecal egg count
FHP	Fasting heat production
FI	Feed intake
FLIAC	Feedlot Industry AccreditationCommittee
FMD	Foot and Mouth disease
FSH	Follicle stimulating hormone
FTAI	Fixed time artificial insemination
GDP	Gross domestic product
GHG	Greenhouse gas
GIPSA	Grain Inspection, Packers and Stockyards Administration
GM	Gross margin
GMO	Genetically modified organism
GnRH	Gonadotrophin-releasing hormone
GST	Goods and services tax
HACCP	Hazard Analysis Critical Control Points
HGP	Hormonal growth promotants
HI	Heat imcrement
HLI	Heat load index
HRI	Hotel, restaurant and institution
HSCW	Hot Standard Carcass Weight
HTLP	High temperature and low pH
IBK	Infectious bovine kerato-conjunctivitis
ID	Identification
IFAD	International Fund for Agricultural Development
IGF1	insulin-like growth factor
IMF	Intramuscular fat
INT	Percentage cost of borrowed capital
IRM	Integrated Resource Management
ISAG	International Society of Animal Genetics
IV	intravenous
JD	Johnes disease
JIVET	Juvenile in vitro fertilisation and embryo transfer

KPI	Key performance indicators
LEM	Late embryonic mortality
LFTB	Lean, finely-textured beef
LH	Luteinising hormone
LSU	Livestock unit
LW	Liveweight
MAP	Mycobacterium avium subspecies paratuberculosis
MAP2	Modified atmosphere packaging
MD	Mucosal disease
MEA	Millennium Ecosystem Assessment
MFN	Most favoured nation
MJ	Megajoules per kilogram dry matter
MLA	Meat and Livestock Australia
MOET	Multiple ovulation and embryo transfer
MSA	Meat Standards Australia
MSTN	Myostatin
NAFTA	North American Free Trade Agreement
NAMP	National Arbovirus Monitoring Program
NAPCo	North Australian Pastoral Company
NCCAW	National Consultative Committee on Animal Welfare
NCD	Neonatal calf diarrhoea
NDF	Neutral detergent fibre
NFAS	National Feedlot Accreditation Scheme
NFI	Net feed intake
NIAJ	National Improvement Association of Japan
NIR	Near Infrared Scanning
NLIS	National Livestock Identification System
NPN	Non-protein nitrogen
NPV	Net present value
NSAIDS	Non-steroidal anti-inflammatory drugs
NT	Northern Territory
NTB	Bali region of Indonesia
NTT	Nusra region of Indonesia
NVD	National Vendor Declaration
NVDF	National Vendor Declaration Forms
OCD	Osteochondrosis desiccans
OIE	Office International des Epizooties, now World Organisation for Animal Health
OSCC	Ocular carcinoma squamous cell or eye cancer
OTH	Over-the-Hooks
OWSWF	Old World Screw worm fly
P8	Rump site
PAYG	Pay as you go
PEM	Polioencephalomalacia
PI	Persistently infected
PI3	Parainfluenza-3
PPAI	Post-partum anoestrous interval
PPF	Production-possiblity frontier
PSDP	Premature spiral deviation of the penis
PSDSK	Indonesian beef cattle and buffalo self-sufficiency program
PSPK	Indomesian data collection of beef cattle, dairy cattle and water buffalo
PTIC	Pregnancy tested in calf
QA	Quality assurance
QTL	Quantitative trait loci
RBY	Retail beef yield
RDP	Rumen degradable protein
RFI	Residual feed intake
RFID	Radio frequency identification
RGS	Ryegrass staggers
RI	Refrigeration Index
RLM	Returns to labour and management
ROE	Return on owner’s equity
ROI	Return on investment
ROTC	Return on total capital
ROTCM	Return on total capital managed
RSPCA	Royal Society for the Prevention of Cruelty to Animals
RUE	Rainfall use efficiency
SARA	Subacute ruminal acidosis
SAU	Standard animal unit
SCU	Standard cattle unit
SNP	Single nucleotide polymorphism
SPA	Standardised performance analysis
SUSENAS	Indonesian National socio-economic household survey
TFP	Total factor productivity
TGM	Total gross margins
TMW	Target mating weight
UDP	Undegraded dietary protein
USA	United States of America
USDA	USA Department of Agriculture
VFA	Volatile fatty acids
VFC	Very fast chilling
VFI	Voluntary feed intake
WA	Western Australia
WDGS	Wet distillers grains plus solubles
WTO	World Trade Organisation
WUE	Water use efficiency
YE	Yield estimate
YG	Yield grades

Index