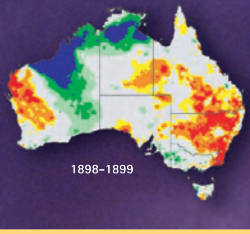
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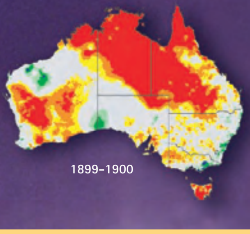
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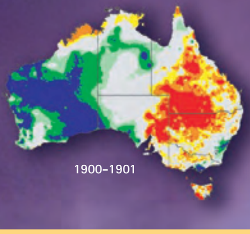
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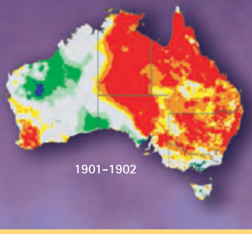
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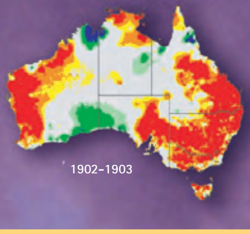
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PASTURE DEGRADATION AND RECOVERY IN AUSTRALIA'S RANGELANDS

Learning from History

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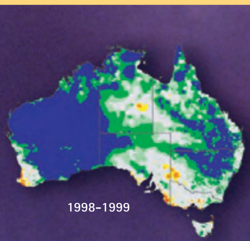
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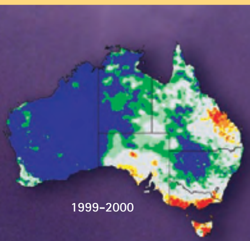
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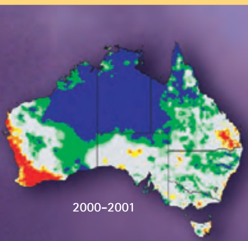
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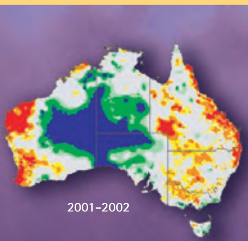
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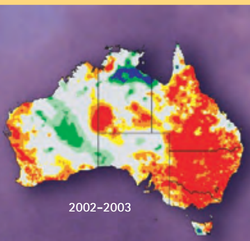
2002–2003

PASTURE DEGRADATION AND RECOVERY Learning from History

PASTURE DEGRADATION AND RECOVERY IN AUSTRALIA'S RANGELANDS

Learning from History

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CVAP
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Dedication:

We have dedicated this report to individual scientists whose work directly influenced the emerging understanding of the interaction of climate and rangeland management described here: Barry White who in 1978 showed that the impact of climatic variability on pasture, animals, cash flow and government policy could be quantified and better managed; Neville Nicholls who during the 1982 drought, showed that the El Niño – Southern Oscillation (ENSO) could be used to forecast Australian rainfall and that Australia is a land of 'droughts and flooding rains' because ENSO amplifies our rainfall variability; Dean Graetz who in 1984, through the television program, *Heartlands*, publicly highlighted past and current environmental damage; Bill Burrows who challenged the grazing industry and government to understand the ecological issues involved in rangeland use; and John Leslie and Barry Walker, who in 1986 invested in the scientific capability to deliver these emerging insights to the community and government.

Department of Natural Resources, Mines and Energy, Queensland
May 2004

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Foreword

The publication of this report will be welcomed as an important synthesis of the history of climate and grazing in Australia's rangelands. Several of the principal investigators are, or have been, scientists in the Queensland Department of Natural Resources, Mines and Energy. Their involvement in this national project supported by national organisations (Australian Greenhouse Office, Department of Agriculture, Fisheries and Forestry–Australia and Australia's Rural Research and Development Corporations through the Climate Variability in Agriculture Program) reflects the Queensland Government's commitment to stewardship of Queensland's natural resources.

There is a need for a strong stewardship responsibility by everyone involved in natural resource management. The effective use of information, science and technology provides the basis of many Departmental activities, including our work with the landholders managing the resource. The science programs undertaken within Natural Resources, Mines and Energy and other State departments in Australia demonstrate the commitment to sustaining the national pasture resource and managing for climate variability, particularly in periods of drought.

The severity of the recent and current drought in regions of eastern and western Australia, including the obvious hardship for people, communities and their animals, coupled with dramatic events such as dust storms, raises the important questions of what is the current risk of degradation to the pasture resource and what role the government has in reducing that risk.

This report describes the analysis of eight major degradation episodes that have occurred over the last hundred years across Australia's rangelands. From this analysis various systems are being researched and made operational, including:

- the provision of better climate risk assessment tools for graziers;
- the use of pasture growth models to calculate degradation risk and safe carrying capacity;
- the use of remote sensing to monitor pasture cover, and identify areas of increased risk of erosion and weed invasion; and
- supporting extension material on better grazing land management options.

This report provides a powerful basis for future work, and its review of the history of drought and degradation challenges us not to repeat the mistakes of the past.

To use the rhetoric of the lead authors, the challenge now is to 'prevent the next degradation episode'.

T Hogan

Terry Hogan
Director General
Queensland Department of Natural Resources, Mines and Energy
May 2004

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Acknowledgments

Preparation and publication of this book have been supported by Queensland Department of Natural Resources, Mines and Energy through Natural Resource Sciences; the Australian Government through the Australian Greenhouse Office; and Agriculture, Fisheries and Forestry–Australia and Australia's Rural Research and Development Corporations under the Climate Variability in Agriculture Program.

This report describes progress towards a better understanding of the roles of climate and management in rangeland condition. It combines the experience of many researchers, some retired, across several State agencies and institutions, and would not have been possible without the generous and open sharing of the wealth of scientific information and observations from the network of committed rangeland scientists and graziers.

We gratefully acknowledge the project funding support of the Australian Greenhouse Office and the Climate Variability in Agriculture Program (Agriculture, Fisheries and Forestry–Australia and Australia's Rural Research and Development Corporations), and all State agencies that supported staff through the project. In particular, Queensland Department of Natural Resources, Mines and Energy and Department of Agriculture Western Australia supported the principal investigators. We wish also to acknowledge our 'patrons' who supported the project over the last seven years, Angela Gillman, Leigh Glover, Kay Abel, Jacqui Willcocks, Anne Brady, Jake Gillen, Ashley Fuller and Barry White.

Funding for the publication was provided by Natural Resource Sciences, Queensland Department of Natural Resources, Mines and Energy and the Australian Greenhouse Office and is gratefully acknowledged, especially the support of Chris Robson and Jo Mummery. Without their funding support the report would not have been able to be distributed so widely.

The lead authors are happy to acknowledge the support and affiliation of the Cooperative Research Centre for Greenhouse Accounting; the Centre for Management of Arid Environments; and the School of Natural and Rural Systems Management, University of Queensland.

This report would not have been possible without the goodwill and collaboration of scientists affiliated with the AussieGRASS project (www.LongPaddock.qld.gov.au), in particular, those representing the Queensland Department of Primary Industries and Fisheries; New South Wales Agriculture; Department of Agriculture Western Australia; New South Wales Department of Infrastructure, Planning and Natural Resources; South Australian Department of Water, Land and Biodiversity Conservation; and the Northern Territory Department of Business, Industry and Resource Development.

The project has had the continuing support of our many colleagues in the Queensland Departments of Primary Industries and Fisheries and Natural Resources, Mines and Energy. In particular, Bill Burrows, David Cobon, Peter Johnston, David Mayer, David Orr, Peter O'Reagain, Col Paull, Tony Pressland, Mick Quirk and Joe Scanlan contributed generously to the project reports.

Scientists in the CSIRO Division of Sustainable Ecosystems (Nick Abel, Gary Bastin, Margaret Friedel, Ken Hodgkinson, John McIvor, Jim Noble and Geoff Pickup) provided much needed support and advice throughout the project. In particular Mark Stafford Smith, Andrew Ash and Mark Howden helped formulate the original project concept and funding proposal.

We are grateful to the Art Gallery of New South Wales, the National Gallery of Victoria and the artist's family for kindly granting permission for reproduction of four works of the artist, Sir Russell Drysdale (1912-81).

The editorial and presentation skills of Natural Resource Sciences technical publishing group provided much-needed support for final publication.

The extensive review of the rangeland literature would not have been possible without the enthusiastic support of the library staff of Queensland Departments of Primary Industries and Fisheries and Natural Resources, Mines and Energy. In particular Helen Chamberlain found many obscure documents relevant to the project.

We are pleased to acknowledge our colleagues and associates in the Climate Impacts and Natural Resource Systems (CINRS) group of Queensland Department of Natural Resources, Mines and Energy who contributed extensive scientific and technical expertise, and also advice and support in the production of the project reports and final publication. The collegiate support of CINRS staff provided a safe home for the project over the last seven years. In addition to staff who contributed material to the report, we thank our colleagues for responding to the risk of a '9th Degradation Episode' occurring in Queensland (2001-03), whilst we were writing the report on the previous eight episodes. David Ahrens, Ken Day, John Carter, Steve Crimp and Dorine Bruget maintained real-time analysis of the emerging drought and climate risk assessment. Robert Hassett provided real-time field monitoring of resource condition across Queensland. Col Paull and Alan Lauder provided invaluable practical insights of the emerging drought. Mathew Byrne, Lisa Collett, Cheryl Taube and Neil Flood demonstrated the potential for monitoring bare ground and pasture burning with remote sensing, while Jozef Syktus and Robert Young evaluated Global Climate Modelling in terms of forecasting drought and flood. Lindsay Brebber kept the super computer going through all this activity. Chris Chilcott, Grant Fraser, Jo Owens and Peter Timmers provided modelling analyses for grazing management guidelines. The SILO team (Alan Beswick, Keith Moodie, Dave Rayner) has always been ready to supply up-to-date climate data. Michael Gutteridge supplied the masks for relevant rangeland regions to provide aggregated rainfall. Cindy Trevor and John Henry provided a detailed last-minute manuscript reading. Jacqui Willcocks and Marvin Polwarth checked many quotations.

Alan Peacock enthusiastically provided web design and availability, and illustrations for reports and publications throughout the project's life. We thank Ken Brook, group leader of CINRS, who provided the managerial environment that made the project possible.

Tracy Van Bruggen over the last seven years provided tireless work, tolerance, chocolate and good humour without which the publication of the report, the delivery of two final reports and the many milestone reports would not have been possible.

Finally, we thank our families for their tolerance, understanding, love and patience. Now we can go home.

Postscript:

Sadly two of the authors lost inspiring parents (Eunice Stone and Terry McKeon) during the writing of the report and we wish to acknowledge their guidance and wisdom.

Preface

The purpose of the report is to provide reference material for those responsible for grazing land management and its environmental consequences. From our own operational activities in climate risk assessment and grazing management in Australia's rangelands over the last 20 years, we had derived the need to collate and review some of the degradation episodes in Australia's rangelands. Drought/degradation episodes in the rangelands not only affected all components of the resource (domestic livestock, native flora and fauna, soils and biodiversity) but all those living and deriving income from the resource (indigenous people, rural communities and governments) (Condon 2002). In this report we have confined our analysis to the impact on the resource from a grazing-use perspective, but we recognise the much wider impacts, and urge fellow researchers to take up the challenge of addressing the extensive environmental and social impacts of these episodes.

This report builds on two previous reports: G.M. McKeon and W.B. Hall (2000) *Learning from history: Preventing land and pasture degradation under climate change* (Final report to the Australian Greenhouse Office, ISBN 0 7345 1603 7) and G.M. McKeon and W.B. Hall (2002) *Learning from history: Can seasonal climate forecasting prevent land and pasture degradation of Australia's grazing lands?* (Technical Report for the Climate Variability in Agriculture Program, ISBN 0 7345 1780 7). The major findings of these two reports have been reviewed and updated and are presented here.

The eight historical episodes described in this report represent a failure to manage for the extreme climate variability that characterises Australian grazing lands. Thus, they represent an historical 'test bed' for our current scientific understanding of rangelands and government/industry response.

At the time of writing (2003), much of Australia is in the grip of drought and, in addition to contractual and accounting deadlines, we were conscious that our research and operational efforts should be directed to the current drought issues. The El Niño of 2002 and the highest daytime temperatures in the available instrumental record (i.e. since 1910) have combined to produce an extreme drought. Previously during the late 1990s, a sequence of good years (1998-2000) in many locations supported a buildup of livestock numbers and other herbivores. For some regions in eastern Australia, the 2002 El Niño came on the back of the 2001/02 drought year and, in combination with high herbivore numbers, was likely to have resulted in high grazing pressure, raising concern of the possibility of another degradation episode.

The early signs of degradation of the pasture resource and extreme drought (extensive areas of bare ground, dust storms, delayed recovery of perennial native pastures, death of native trees) are apparent. However, we are aware that our science is not yet good enough to address the multiplicity of controversial issues arising from this drought such as:

1) quantification of the resource damage due to domestic livestock numbers in contrast to the effects of extreme climatic variability and high populations of kangaroos;
2) the quantification of global warming/greenhouse effects on Australia's climate in comparison to the natural background variability of the climate system which occurs on inter-annual, decadal and longer timescales;
3) the development of climate forecast systems for prediction of climate anomalies ranging from seasonal extremes of drought or flood to decadal variability of wet or dry sequences of years; and

4) the development of economic forecast systems that reduce the impacts of fluctuating global commodity prices of wool and meat on pastoral enterprises.

Nevertheless, this report documents that we do have some forecasting capability. Some of the year-to-year variability in rainfall is understood to be driven by the Pacific Ocean. Whilst climate forecasting systems using this information are not expected to be totally accurate, they at least provide the tools for rational climate risk assessment using historical rainfall records. However, our preoccupation with El Niño and La Niña has diverted attention from other possible causes of extended drought and wet periods. This report aims in part to redress this imbalance.

The causes of degradation and recovery are also well understood. The combination of drought and heavy utilisation, due to both domestic livestock and other herbivores (rabbits, kangaroos), leads to the accelerated death of perennial vegetation, loss of surface soil protection and delayed recovery from drought. History indicates that several management options have proved successful: conservative stocking rate, management of total grazing pressure, early response to drought by reducing stocking numbers, and management for pasture recovery. To these we could add climate risk assessment based on the emerging understanding of the causes of climate variability. We are also enthused by increased interest over the last decade in grazing land management in the grazing community, with particular attention to quantifying tactical stocking rate decisions, and long-term carrying capacities.

At the time of writing there is a strong scientific consensus that the observed increase in atmospheric concentrations of greenhouse gases is driving global warming. However, the future impacts on Australia's rainfall are uncertain. We believe the best scientific tools available to us are the Global Climate Models but their science is still in its relative infancy and many of the potential drivers of the climate system are yet to be adequately represented or 'parameterised'.

Thus, we are racing into an uncertain climatic future, perhaps on a collision course with future climatic extremes. Whether the grazing industry and the wider community successfully adapt to future climate extremes/variability will depend on how well we use the knowledge of the past degradation (and recovery) episodes described in this report to avoid repeating the mistakes of the past.

This report was prepared during 2003 in the then Department of Natural Resources and Mines which has subsequently expanded to the Department of Natural Resources, Mines and Energy.

G.M. McKeon, W.B. Hall, I.W. Watson, G.S. Stone and B.K. Henry

Authorship

This report covers both a wide range of scientific disciplines (meteorology, climatology, ecology, land management, land degradation processes) and Australia-wide grazier experiences across many locations and vegetation types. In response to this complexity, over the last seven years we have sought expert opinion and review from scientists in these disciplines and from graziers managing current conditions. The report has been built on these individual and original contributions. To address the considerable risk that the authorship of these contributions would be lost or diluted we have indicated lead and contributing authors, and chapter reviewers.

Summary

G.M. McKeon, I.W. Watson, W.B. Hall, B.K. Henry, S.B. Power and G.S. Stone

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Mechanisms of degradation in grazed rangelands – Woody weeds: R.W. Condon, D.R. Green, J.O. Carter and W.H. Burrows

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Episode 6: Central Australia in the 1960s: G.N. Bastin and J.R. Purvis

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Selected illustrative examples of rangeland communities

a. Mulga pastures (south-west Queensland) in good condition with high grass basal area and surface soil cover interspersed between mulga clumps.

b. Mulga pastures (south-west Queensland) in poorer condition with thickets of mulga regrowth, lack of grass and surface cover, and emerging woody weed understorey.

c. Chenopod shrublands (western New South Wales) in good condition with high density of shrubs interspersed with new growth and ephemeral species.

d. Chenopod shrublands (western New South Wales) in poor condition with reduced shrub density and showing evidence of severe wind erosion.

e. Open woodland (north-eastern Queensland) in good condition with high grass basal area and soil surface cover.

f. Open woodland (north-eastern Queensland) in poorer condition with emerging patches of bare ground and increased density of young saplings.

Photos by Robert Hassett (Pasture and land assessment officer, Natural Resource Sciences, Queensland Department of Natural Resources, Mines and Energy).

Summary

G.M. McKeon, I.W. Watson, W.B. Hall, B.K. Henry, S.B. Power and G.S. Stone

Introduction

Droughts are inevitable in Australia's rangelands. Yet, despite the physical hardship, the social heartbreak, the animal suffering, the financial and economic consequences, and the environmental damage we know for certain will occur, we appear to be surprised by the next inevitable drought.

The work in this report has been motivated by the proposition that Australia's rangelands used for livestock grazing will be better managed for future climatic variability (and climate change) by better understanding the mistakes and successes of the past. Since 1956 Australia's rangelands have carried 8–14 million cattle and 18–40 million sheep (National Land and Water Resources Audit 2001). The benefits to Australia of improving our management of the rangelands, especially during drought, are immense – over 3.2 million km^2 of rangelands (more than 43% of Australia) are used for livestock grazing and much of this area has been affected by degradation to some extent.

The manifestations of land and pasture degradation, described in Chapter 1, are the loss of 'desirable' (in terms of providing feed for livestock) perennial grasses and shrubs, the resulting increase in soil erosion (both wind and water-driven), soil structural decline and infestation of woody weeds. Perennial species (usually grasses but also palatable shrubs in some areas) are the key to economic and resource sustainability. They not only provide drought forage in variable rainfall climates such as Australia's, but they also protect the soil surface, play an important role in nutrient cycling and maintaining soil 'health' (e.g. soil organic matter), and in some areas provide fuel for burning to help control woody weeds.

Excessive grazing pressure and climatic variability interact to cause the loss of 'desirable' perennial grasses and shrubs. Results of grazing trials and grazier experience have shown that the combination of heavy utilisation and drought during what should have been the normal growing season results in the loss of 'desirable' perennial plants. The loss of perennial cover leads to increased soil erosion, and reduced fuel to support pasture burning, with resultant woody weed infestation and further pressure on the grazed resource. Recovery of vegetation generally requires sequences of above-average rainfall years and low grazing pressure to allow plant populations and perennial root systems to build up.

In Chapters 1 and 2, this report describes eight major degradation episodes from across Australia's grazed rangelands (Table 1). Drought is an important component of these episodes, revealing the extent of degradation and also contributing to further degradation. The purpose of describing these episodes is to derive an understanding of what caused land and pasture degradation, and what actions and information sources are needed to prevent future episodes. Recovery sometimes occurred decades after the degradation episode, although it has not been possible to quantify the extent to which initial productivity and resource condition have been restored. In episodes where there has been considerable loss of soil and/or woody weed increase, irreversible change may well have occurred and the return to initial productivity for grazing is unlikely to occur. The report is not intended as a history, but uses the review of previous histories (e.g. Condon 2002) to help interpret the causes of degradation.

The initial review of these degradation episodes and subsequent partial recovery confirmed the obvious. Year-to-year variation in rainfall was a major factor driving both degradation and recovery. However, it is simplistic to focus on the lack of rainfall as the major cause of the degradation episodes. Some

Table 1. Regional degradation episodes in Australia's rangelands as described in detail in Chapter 2. The extended drought period associated with each degradation episode was calculated using regional rainfall for a standard 12-month period from 1 April to 31 March (Chapter 1). The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean. The drought was considered broken when average to well above-average rainfall occurred. For Episode 5 which involved woody weed infestation in the 1950s, the impact was not revealed until the later drought period of the 1960s.

Episode	Degradation episodes	Extended drought period
1	1890s in western New South Wales involving soil erosion, the impact of woody weed infestation, rabbit plagues, substantial financial losses and financial hardship resulting in the Royal Commission of 1901 (Anon. 1901, Noble 1997a)	1898/99 – 1902/03
2	1920s–30s in South Australia involving substantial loss of perennial vegetation and soil erosion (Ratcliffe 1936, 1937) resulting in government legislation for regulation of carrying capacity (Donovan 1995). Western New South Wales was also affected	1925/26 – 1929/30
3	1930s in Gascoyne region of Western Australia involving substantial loss of perennial shrubs, soil erosion and animal losses documented in the Royal Commission of 1940 (Fyfe 1940, Wilcox and McKinnon 1972) and subsequent inquiries (Jennings *et al.* 1979)	1935/36 – 1940/41
4	1940s in western New South Wales involving substantial dust storms and animal losses graphically portrayed in Russell Drysdale's paintings and Keith Newman's newspaper reports (Condon 2002) and supporting the need for government action (Beadle 1948)	1941/42 – 1944/45
5	1950s in western New South Wales involving large increases in woody weeds resulting in reduced carrying capacity and income in the 1960s (Anon. 1969, Hodgkinson *et al.* 1984)	1964/65 – 1967/68
6	1960s in central Australia involving wind and water erosion resulting in extensive surveys and re-assessment of carrying capacity (Condon *et al.* 1969a, 1969b, 1969c, 1969d, Purvis 1986)	1958/59 – 1965/66
7	1960-70s in south-west Queensland involving soil erosion and woody weed infestation resulting in the government-sponsored South-West Strategy supporting review of recommended carrying capacities and property amalgamation (Warrego Graziers Association 1988, Johnston *et al.* 1996a, 1996b)	1964/65 – 1967/68
8	1980s in north-east Queensland involving soil erosion and loss of 'desirable' perennial grasses, resulting in extensive government-sponsored surveys (De Corte *et al.* 1994) and dramatic grazier response (Landsberg *et al.* 1998)	1984/85 – 1987/88

commentators, even today, view it as the sole cause. However, drought on its own does not cause degradation of the scale described here. Drought has been a feature of Australian landscapes for tens or hundreds of thousands of years. The rangeland ecosystems of Australia have adapted to drought and have probably weathered droughts far worse than have been encountered since European settlement (e.g. Hendy *et al.* 2003).

The main feature of degradation in the documented episodes was the carrying of too many animals, for too long, on areas especially under stress from drought. This highlights that the major management issue in natural grazing systems is managing stock numbers. The challenge is to optimise economic performance, yet at the same time matching stock numbers to available feed (e.g. Bartle 2003a, 2003b) and reducing resource degradation risk. This must be done within a highly variable and unpredictable environment in terms of rainfall and prices. Furthermore, the 'animals' can include domestic livestock, native herbivores (such as kangaroos), and feral herbivores (such as rabbits and goats). A problem that graziers have in managing grazing pressure is that they only really have good control over domestic livestock.

This report considers factors that led to the excessive grazing pressures which resulted in degradation. For each of the eight degradation episodes, various factors are considered. They include the rise in livestock numbers and also rabbit and kangaroo grazing pressure. This was due to several factors including years of high rainfall prior to the droughts, government policy at the time to ensure the land was fully stocked, over-expectation of the carrying capacity of the land, and a physical and/or economic inability to destock the land quickly when feed ran out.

The socioeconomic and biophysical contexts within which degradation occurred are also reviewed. Global economic and political forces had major impacts on prices, which were a significant factor in managing stock numbers. Over time, animal husbandry and disease management have improved and livestock were selected for better adaptation to the environment. Improvements in technology have had contrasting impacts. For example, under drought conditions stock can be kept on the land for longer, whilst improved roads and better transport services have made it easier to destock animals when grazing pressures become too high.

Individual property managers make the day-to-day decisions about how many of their animals should run on a piece of land and to a lesser extent what effort can be expended on feral and native herbivore control. No amount of government policy, and no amount of improvements in seasonal climate forecasting, will be of use without individual managers appropriately responding to the conditions. However, managing grazing enterprises is complex. For example, Chapter 4 analyses the history of two western Queensland properties and highlights the difficulties in making correct management decisions when faced with a range of uncertainties in climate and finances. Chapter 4 also provides a property perspective in which we can better understand the regional scale histories found in the review of the eight degradation episodes.

As will be described later, a number of commonalities emerge from the histories we present. The fact that there are common issues arising from these episodes, spaced over nearly a hundred years and across Australia's rangelands, strongly suggests that there are indeed lessons still to be learnt.

The eight degradation episodes

The eight degradation episodes include examples from all the rangeland States and the Northern Territory (Table 1). They are not the only degradation episodes to have occurred since settlement, but were chosen because they were well documented in a range of sources including Royal Commissions, personal accounts, newspaper records and government reports.

These sources provided us with the context for the social, political, animal welfare, economic and environmental issues from the time, as well as with data on changes in stock numbers and commodity prices, and assessments of the extent of degradation. We then combined this information with time series of climatic forcings, rainfall and simulations of historical pasture growth using present-day methods to build up a composite picture of each degradation episode and the factors that led to it.

'Drought' was the major issue for people at the time of the episodes, and hence it was the starting point of our analysis. However, in most cases the sequence of dry years, ranging from two to eight years, exposed and/or amplified the degradation processes that were already in train. The evidence for degradation is unequivocal. The accounts from the time are graphic in their descriptions of the physical 'horror' of bare landscapes, erosion scalds, gullies and dust storms. Subsequent observations documented the environmental and economic damage caused by woody weeds, loss of palatable perennial species and soil loss, and highlighted the animal suffering through deaths or forced sales. For example, Webster (1973 p.150) reported that more than 100 million sheep died in 'the eight severe droughts that have affected the Australian pastoral industry since 1880'. Importantly from the human perspective, several accounts have described the financial and emotional plight of graziers and their families during drought, leading to abandonment of properties or, sadly, deaths (e.g. Ker Conway 1989, McDonald 1991). Studies during the recent 1990s drought in Queensland and New South Wales confirm the hardship that drought causes (Stehlik *et al.* 1999).

Climate forcings

Imagine the benefits to Australia if these episodes could have been prevented or at least minimised through forewarning. Seasonal forecasting based on a sound understanding of the climatic drivers of rainfall in the rangelands provides opportunities for alerting us to potential future degradation episodes.

This report examines current knowledge of a number of phenomena that affect climate variability in Australia's rangelands. These influences are complex and current climatological research has shown that there are significant climatic signals at timescales from about biennial to decadal and multi-decadal (White *et al*. 2003). The best known of these is the El Niño – Southern Oscillation (ENSO) phenomenon (Pittock 1978, Partridge 1991, Allan *et al*. 1996b). ENSO has a well-described dominant effect on year-to-year variability in Australia's rangelands (Lindesay 2003).

El Niño years, when the eastern Pacific is anomalously warm, are generally associated with an increased chance of below-average rainfall, especially in Queensland and New South Wales, and to some extent through central Australia and the Western Australian rangelands as well. In contrast, La Niña years, when the eastern Pacific is anomalously cold, provide an increased chance of above-average rainfall in the same areas. The Southern Oscillation Index (SOI) is a widely available and simple measure for summarising ENSO patterns. Winter/spring SOI values below 'minus five' reflect El Niño years and values greater than 'plus five' reflect La Niña years (e.g. Clewett *et al*. 1991, Allan *et al*. 1996a).

When we started assembling the history of the various degradation episodes in 1996, our purpose was to understand the major climate drivers that had led to the extreme wet and drought sequences, with particular attention to ENSO. At that time, the first research on the effects on Australian rainfall of inter-decadal signals in the Pacific Ocean was being done (Power *et al.* 1999). We have built on the analysis of Power *et al.* (1999) to place the historical degradation episodes in the context of what has happened in the Pacific Ocean on decadal timescales. Measures of the inter-decadal oscillation have been developed by the UK Meteorological Office (Inter-decadal Pacific Oscillation, IPO) and the University of Washington (Pacific Decadal Oscillation, PDO). Both ENSO and the IPO/PDO were shown to be associated with the large year-to-year variation in rainfall and pasture growth across much of Australia's rangelands.

The interaction of ENSO and the IPO/PDO adds to the complexity of understanding rainfall variability. A major finding was that, in eastern Australia, the impact of La Niña years has been greatly enhanced when the inter-decadal component of the Pacific Ocean variability was in a mode characterised by a very large wedge-shaped body of cold water dominating not only the equatorial region of the eastern Pacific, but also extending into the extra-tropical regions of the northern and southern hemispheres (IPO cool). However, the interaction of inter-decadal indices and El Niño varied considerably with location across the rangelands (Chapter 1).

Indices of the IPO/PDO were *warm* for most of the period from 1925 to 1946 and *cool* for most of the period from 1947 to 1976, and hence provide supporting evidence for the shift in climate regimes that has been identified as a contributor to the recovery of vegetation, for example, in western New South Wales and South Australia. In eastern Australia and to a lesser extent other regions, the major periods of potential pasture recovery have been associated with the *cool* phase of the IPO/PDO when sequences of above-average rainfall years have occurred (mid 1950s, early 1970s, and perhaps late 1990s). Most of the degradation episodes occurred when the IPO/PDO indices were *warm* or neutral when the chance of 'drought-breaking' (above-median) rainfall was not as high as the *cool* phase.

The various Pacific Ocean indices such as ENSO and IPO/PDO account for only 20–40% (Crimp and Day 2003) of the year-to-year variability in rainfall in the regions of major influence (e.g. in Queensland). A small proportion (23%) of years in the extended drought periods in eastern Australia (Table 1, Chapter 1.2.3) were associated with El Niño. Thus the impact of sequences of non-El Niño drought or dry years in the historical degradation episodes has been more devastating than isolated El Niño droughts and hence the lack of predictive capability remains a serious limitation to our capacity for useful climate risk assessments. It is plausible, however, that at least some of these droughts were due to the inherently chaotic nature of the atmosphere, and events of this kind may be essentially unpredictable. There is clearly a need to research other causes of rainfall deficit. Nevertheless, whilst there is still some way to go to provide adequate climate risk assessment, we believe that the understanding of Pacific Ocean effects on rainfall is useful for climate risk management, especially interpretation of why sequences of wet or dry years occur.

While there has clearly been a statistical association between rangeland rainfall variability and the IPO/PDO, and an association between IPO/PDO and the impact that ENSO has had on Australia, the dynamics of the IPO/PDO are not yet fully understood. It is not clear if these associations are causally related, nor is it clear if the IPO/PDO is predictable or persistent on decadal timescales. Frustratingly for rangeland managers and scientists alike, the various components of the climate system operating at different timescales are yet to be unravelled. At the time of writing (2003) we cannot even be certain what stage the late 1990s/early 2000s are in terms of inter-decadal variability (e.g. Mantua and Hare 2002). What is clear, however, is that the impact that ENSO has had on Australia has waxed and waned from decade to decade and from generation to generation. This variability can manifest itself in many forms, e.g. in a reduced number of La Niñas and/or El Niños occurring in a given decade. Given the anthropogenic changes occurring in the climate system there is uncertainty as to the direction and magnitude of future inter-decadal variability of this kind (e.g. Walsh *et al*. 1999, Cai and Whetton 2000). It is hoped that current research into the IPO/PDO will ultimately underpin improved seasonal to inter-annual climate forecasts, and answer the questions of how well we will be able to foretell that a particular decade will exhibit an increased frequency of El Niños or La Niñas or that a particular decade may be more climatically primed to be at greater risk of a degradation episode.

The understanding of these climatic forcings has provided the opportunity to develop climate forecast systems. For example, forecast systems based on the SOI or sea surface temperatures (SSTs) (McBride and Nicholls 1983, Stone *et al.* 1996, Drosdowsky and Chambers 1998, Drosdowsky 2002) now allow climate risk assessment based on historical rainfall data. The National Climate Centre of the Bureau of Meteorology (BoM) provides three-monthly forecasts based on SSTs (http://www.bom.gov.au/). The Queensland Centre for Climate Applications (QCCA) also provides historical probability analyses based on SOI phases (Stone *et al.* 1996) (http://www.LongPaddock.qld.gov.au/). However, the use of information relating to possible decadal and inter-decadal signals for forecasting is still in the experimental stage (e.g. White *et al.* 2003). Similarly Global Climate Models representing many of the physical processes in the climate system have only been operational since 1998 (Goddard *et al.* 2003, http://iri.columbia.edu/climate/forecast/net_asmt/) and hence are still establishing a 'track record'.

If the 'character' of climate variability of the last hundred years is unchanged in the future then, in the working life of a property manager, for example 40 years, an average 10 El Niño years and nine La Niña years are likely to be experienced, as well as extended periods of inter-decadal variability (15 – 20 years). The success of the property enterprise in terms of finances, satisfaction and resource condition will depend on how well climate variability on these different timescales has been managed for. However, not every 'El Niño' has resulted in a drought year nor has every drought been due to 'El Niño'. Thus a major problem for communication is that the current (2003) public emphasis on El Niño will obscure the importance of managing for non-El Niño related drought years.

Since the 1980s, seasonal rainfall forecasting has concentrated on ENSO-related indices (SOI or SST anomalies). However, the analysis and extended drought periods reported in Chapter 1 indicate the importance of the 'neutral SOI' years in contributing to the regional extended drought periods. Forecasting of rainfall anomalies in this 'year-type' provides a major challenge for further research into better forecasts.

The future behaviour of the climate system is complicated by the possible presence of changes due to anthropogenic influences (e.g. increasing greenhouse gasses, ozone depletion, aerosol emissions, land use change) together with naturally occurring inter-decadal variability. Frustratingly, the implications of global warming for rainfall variability remain largely uncertain, and hence analysis of anthropogenic and naturally-occurring influences on rangeland rainfall and pasture growth is an important area of current and future research.

Price variability and other factors influencing the degradation episodes

Variability in rainfall and pasture growth were major factors in each of the degradation episodes presented. However, variability in prices paid for wool and meat also contributed to the degradation outcomes by affecting not only the build-up in numbers, but also the timing and extent of destocking when seasons became dry. For example, wool prices declined by 30% from 1890 to 1894 during a favourable climatic period in eastern Australia. Wool prices increased at the onset of the drought (1897 to 1900) and then halved again in 1901 at the peak of the drought in western New South Wales and south-west Queensland. Sustained price recovery did not occur until after 1904. Similarly wool prices fluctuated in the 1920s, increasing rapidly from 1922 to 1924, then falling by 25% in 1925, and further declining during the years of the Great Depression (early 1930s) with extended drought periods in western New South Wales and South Australia. Similarly, beef prices dropped sharply by 80% in the mid 1970s. Such rapid declines in the prices received by property managers 'encouraged' them to retain stock in the hope that prices would improve. When these periods of relatively low prices coincided with drought conditions such as in the late 1890s in western New South Wales (Episode 1), 1926 to 1930 in eastern Australia (Episode 2) and the mid 1930s in Western Australia (Episode 3), the conditions were set for grazing pressures to be greatly increased and degradation to be exacerbated.

The description of the degradation episodes also highlights the effect of government policy on degradation. In South Australia and Western Australia, governments demanded certain levels of minimum stocking or infrastructure development to discourage squatters or speculators (Donovan 1995, Tynan 2000, Watson, 2002). The wish to provide land for soldier settlers after both World Wars led to the subdivision of large properties into smaller blocks, many of which proved to be too small to provide viable incomes once commodity prices declined, and were consequently overstocked (Drysdale 1995). However, in some regions such as south-western Queensland, surveys have indicated that degradation can be severe across all properties regardless of size (Mills *et al.* 1989).

The importance of management

Managers make the day-to-day decisions that either prevent or accelerate degradation (Wilcox 1988) and promote or inhibit recovery. Learning from the experiences of individual pastoral managers is therefore critical. Those graziers whose experiences have been recorded (e.g. Chapter 4; Anon. 1951, Lilley 1973, Purvis 1986, Lange *et al.* 1984, Landsberg *et al.* 1998, Lauder 2000a, 2000b, Stehlik 2003, Wahlquist 2003) emphasise the adoption of conservative stocking rates and/or highly responsive stock management as strategies to prevent degradation and promote pasture recovery when the opportunity arises. However, the historical degradation episodes show that some graziers have felt compelled, presumably by property size and economics, to push the pasture resource to (or even past) its limit. Nevertheless, it is hard to imagine that any manager, if forewarned of a potential degradation event, would take the risk of animal losses, financial cost, and environmental damage by not reducing stock numbers early.

Degradation alerts will therefore be critical in the future to give managers time to make decisions that will minimise the impact of grazing. Alert systems, based on seasonal forecasting, coupled with stock number data and simulated pasture production, are under development in the Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS) project (Carter *et al.* 2000; http://www.LongPaddock.qld.gov.au/). Simulations of pasture biomass and growth enable an alert to be triggered under conditions likely to result in loss of soil cover, i.e. when high grazing pressure is likely to occur during times of low pasture growth. The objective is to accurately assess animal numbers so as to quantify grazing pressure in real time and to use seasonal climate forecasting systems to calculate probabilities of future pasture growth.

The compilation of long-term records can provide a basis for analysing the impacts of climate variability on grazing enterprises. It also provides a context for examining which grazing management options were successful in the face of variability and which, in hindsight, were mistakes. An example of this approach is found in Chapter 4 for two sheep stations in Queensland that have been successfully managed over very long periods. These two examples demonstrate that, at the property level, lessons were indeed learnt from experience. Managers improved their ability to contend with highly variable climatic and price environments.

Commonalities to emerge: an opportunity to learn

No two droughts and no two degradation episodes are the same, but some commonalities emerge from the eight episodes. It is this repetition of factors, common to events in different places and at different times, that suggests we may reduce future impacts.

1. There was a general over-expectation of safe carrying capacity by managers, investors and governments.
2. Stock numbers and other herbivores (e.g. rabbits, kangaroos and goats), and in some cases woody weed seedlings, increased in response to a period of mainly above-average rainfall that preceded the drought/degradation episode.
3. These above-average years coincided in eastern Australia with the cool phase of the IPO/PDO (early 1890s, 1916–18, early 1920s, mid 1950s, early 1970s, and perhaps late 1990s).
4. Intermittent dry seasons or years resulted in heavy utilisation, damage to the 'desirable' perennial species, and ultimately the grazing land resource. This led to the rapid collapse in the capability of the land to carry animals at the onset of drought.
5. Extreme utilisation in the first years of drought by retaining stock caused the further loss of perennial species, exacerbating the effects of drought in subsequent years.
6. Rapid decline in, or generally low, commodity prices resulted in some managers retaining stock in the hope of better prices or the fear of high cost of restocking.
7. Continued retention of stock through a long drought period compounded damage to the resource and delayed recovery.
8. The sequence of drought years resulted in rapid decline in surface cover, which revealed the extent of previous resource damage and further accelerated degradation processes.
9. In eastern Australia, drought sequences have occurred more often when the IPO/PDO 'indices' were in the *warm* phase.

10. Government surveys, inquiries and Royal Commissions were held during or following drought sequences and documented the economic and environmental damage.
11. Partial recovery occurred during sequences of above-average years sometimes decades after the major degradation episode.

More work to do

The major issue raised by the historical degradation episodes is to what extent they could have been avoided or at least mitigated by better pasture or grazing management. During the severe drought periods of the degradation episodes it was debated whether the apparent soil erosion and loss of 'desirable' perennial shrubs and grasses were the result of the extremes of climatic variability or caused by too many animals. One approach to the debate is to build computer models that represent the impact of climate variability and stocking rate decisions on the pasture resource. In Chapter 3, we present modelling studies for 'desirable' shrub populations in the North East District of South Australia and the Gascoyne region of Western Australia. The simulations highlighted the deleterious impact of high stock numbers and intermittent drought periods on the loss of palatable shrubs. The decline in shrub density was less severe when conservative stocking or responsive tactical stocking decisions reduced grazing pressure on shrubs in critical years. The simulation studies support the view that, for Episodes 2 (South Australia) and 3 (Gascoyne, Western Australia), the severe drought periods revealed and also amplified previous reduction in shrub density. Thus, the simulations suggest that much of the degradation could have already occurred by the time of the episodes described in this report. They also suggest that, with the benefit of hindsight, much of the loss of shrubs and resulting soil loss was avoidable. Chapter 3 also describes the remarkable increase in shrub density in the Gascoyne during the late 1990s in association with well above-average rainfall. The future management of this valuable vegetation resource will demonstrate whether or not managers have learned from history.

Of course, science on its own will have minimal effect in contending with the next inevitable degradation episode. Governments, government agencies and the community need to be prepared for drought. Individual land managers need to be prepared and supported to make the decisions that will ameliorate the impact of the factors leading to degradation. In simple terms, this means the removal of an appropriate number of animals (domestic, feral and native) from the rangeland resource at critical times whilst not jeopardising financial viability (e.g. Stafford Smith and Foran 1992).

This report is, of course, incomplete. It considers eight degradation episodes, but Australia's pastoral rangelands have suffered through more episodes than these. The rangelands have also experienced widespread degradation outside these episodes. Background processes leading to degradation can occur continually and hence 'eternal vigilance' in terms of grazing management is required.

Work remains to fully document the histories of individual properties, to tease out the mistakes and successes of individual pastoral managers and families. The degradation episodes themselves are not yet fully documented. As the work continues we hope that further historical accounts from these times will emerge, adding to our understanding.

Current and future challenges

Better natural resource management decisions are made when managers: (1) understand a problem; (2) have the motivation to adopt a changed practice; and (3) have the capacity to implement it (Gordon *et al.* 2001). While these three principles were developed to represent the decision making of individual land managers, we believe the same principles apply equally well to land administrators and policy makers.

The documentation of the causes of the degradation episodes and consequent human and animal hardship should provide sufficient motivation to want to do things better in the future. We have also discussed the capacity to change, specifically, the use of more accurate and timely forecasts, and more responsive grazing management decisions.

We believe there are three components to preventing degradation of the grazing resource:

1. better resource management, particularly grazing and fire management, by individual managers to help prevent degradation (Campbell and Hacker 2000);
2. government policies and administration which value the responsibility of managers to make day-to-day decisions on their properties as well as providing them with the tools to help improve those decisions (Stafford Smith 2003); and
3. alert systems, at both local and regional scales, that use improved climatic understanding and resource monitoring to provide warnings of the potential for degradation episodes (Carter *et al.* 2000).

Only with these three things in place is preventative action possible and likely to occur.

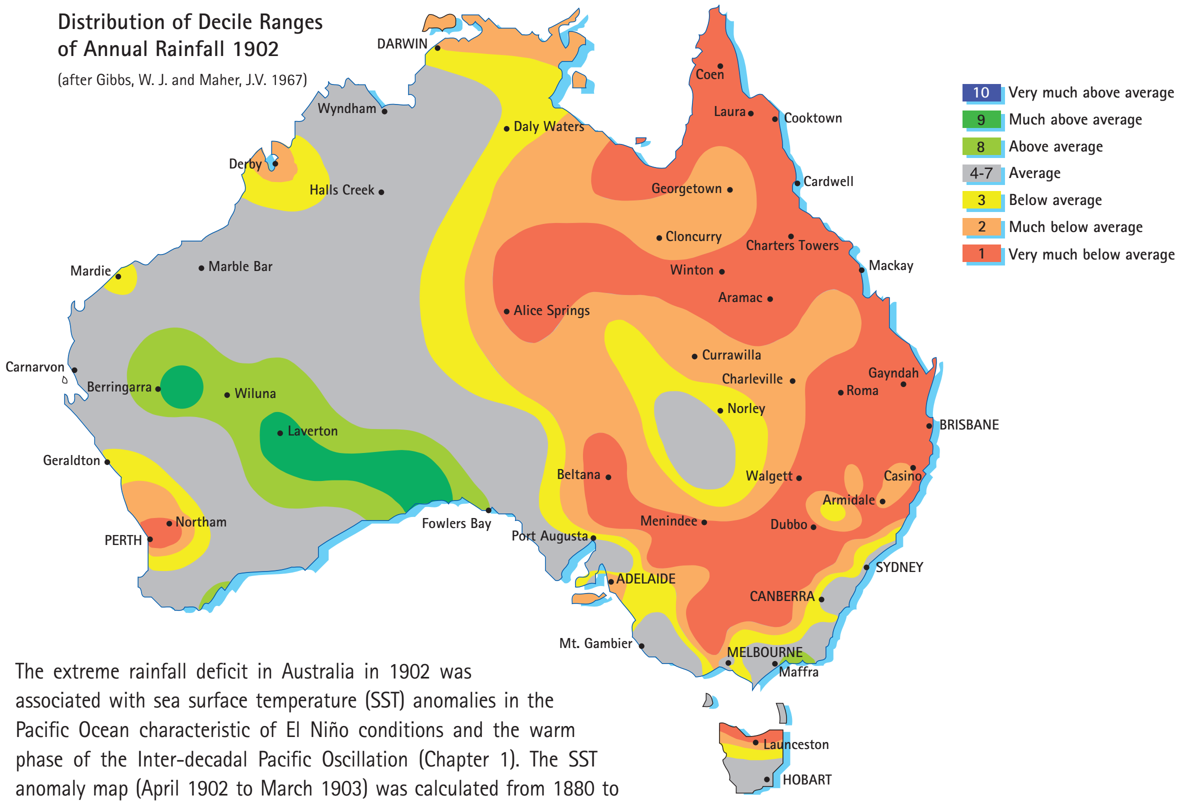
It would seem debatable what 'better grazing and fire management' actually is, especially where the climate has such high year-to-year and decade-to-decade variability, and has uncertain future climate trends. Nevertheless, graziers, their advisers, scientists and governments have all expressed views over the last hundred years on how to best manage the grazed resource (e.g. Donovan 1995, Hacker and Hodgkinson 1995, Johnston *et al*. 2000, Lauder, 2000a, 2000b, Bartle 2003a, 2003b). These views include risk averse strategies (e.g. Purvis 1986, Landsberg *et al.* 1998), preventative and early action prior to and at the onset of drought (Childs 1973a), responsive stock adjustment during drought (Johnston *et al.* 2000, Bartle 2003b), tactical rest to aid recovery (Lauder 2000b), and monitoring for compliance with legislation (Donovan 1995, National Land and Water Resources Audit 2001) and/or commercial advantage. The above list (which is by no means exhaustive) represents an impressive knowledge base gained from hard-won experience and scientific testing. We would be foolish not to use it and continue to build on it to manage for future climate variability.

The need may be more urgent than we think. A series of not unexpected good seasons in Queensland (1999-2001, positive SOI and mainly *cool* PDO) supported an increase in beef cattle numbers (11.3 million in 2001 from 8.5 million in 1988) to levels last seen in 1978 (11.0 million). Although sheep numbers (9.7 million) were relatively low, kangaroo numbers were estimated (Anon. 2003, Kelly 2003) to be very high compared to historical estimates since the 1970s (≈24 million, A. Pople pers. comm.). The retention of high stock numbers in some regions through the dry years of the late 1970s and 1980s contributed to the pasture deterioration and degradation described in Chapter 2 as the 8th Degradation Episode. Will the early 2000s also be documented as a degradation episode?

We are currently presenting the findings from this report '*Learning from History*' to graziers, grazier organisations and government agencies. The presentations continue to outline the potential risk for another degradation episode as the inevitable dry period which began in 2001 was exacerbated by the 2002 El Niño.

Is the 9th degradation episode being prevented? It is too early to tell.

The 1902 drought



Distribution of Decile Ranges of Annual Rainfall 1902

(after Gibbs, W. J. and Maher, J.V. 1967)

The extreme rainfall deficit in Australia in 1902 was associated with sea surface temperature (SST) anomalies in the Pacific Ocean characteristic of El Niño conditions and the warm phase of the Inter-decadal Pacific Oscillation (Chapter 1). The SST anomaly map (April 1902 to March 1903) was calculated from 1880 to 2000 climatology based on the dataset generated by Rayner *et al.* (2003).

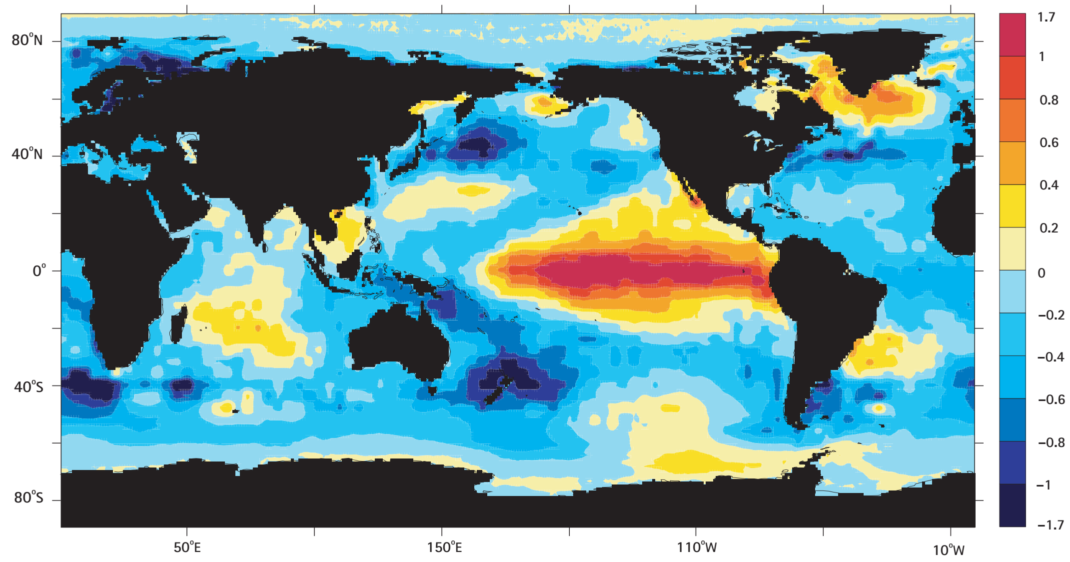
Foley (1957) reviewed the history of droughts in Australia from 'earliest years of settlement to 1955'. He noted the extreme severity of the 'Federation drought' from 1895 to 1903 and commented (p. 99) that for Queensland 'Had the country been as far developed as at the present time it seems very probable that the effects would have by far eclipsed anything that has since happened.'

In summarising this seven-year drought Foley stated (p. 208):

> It is difficult for present day Australia to realise the magnitude of the effects of this drought on the economy of the country. It is usually referred to as the '1902 drought' but in reality it extended over at least seven years. Sheep numbers which had reached 100 million were cut in half and cattle numbers were reduced by 30 per cent.

Recovery of agriculture and pastoralism did occur in most areas over the following decade. However, in western New South Wales livestock numbers never returned to the same level as had occurred in the favourable rainfall of the early 1890s (Beadle 1948, Chapter 2).

SST Anomaly April 1902 to March 1903



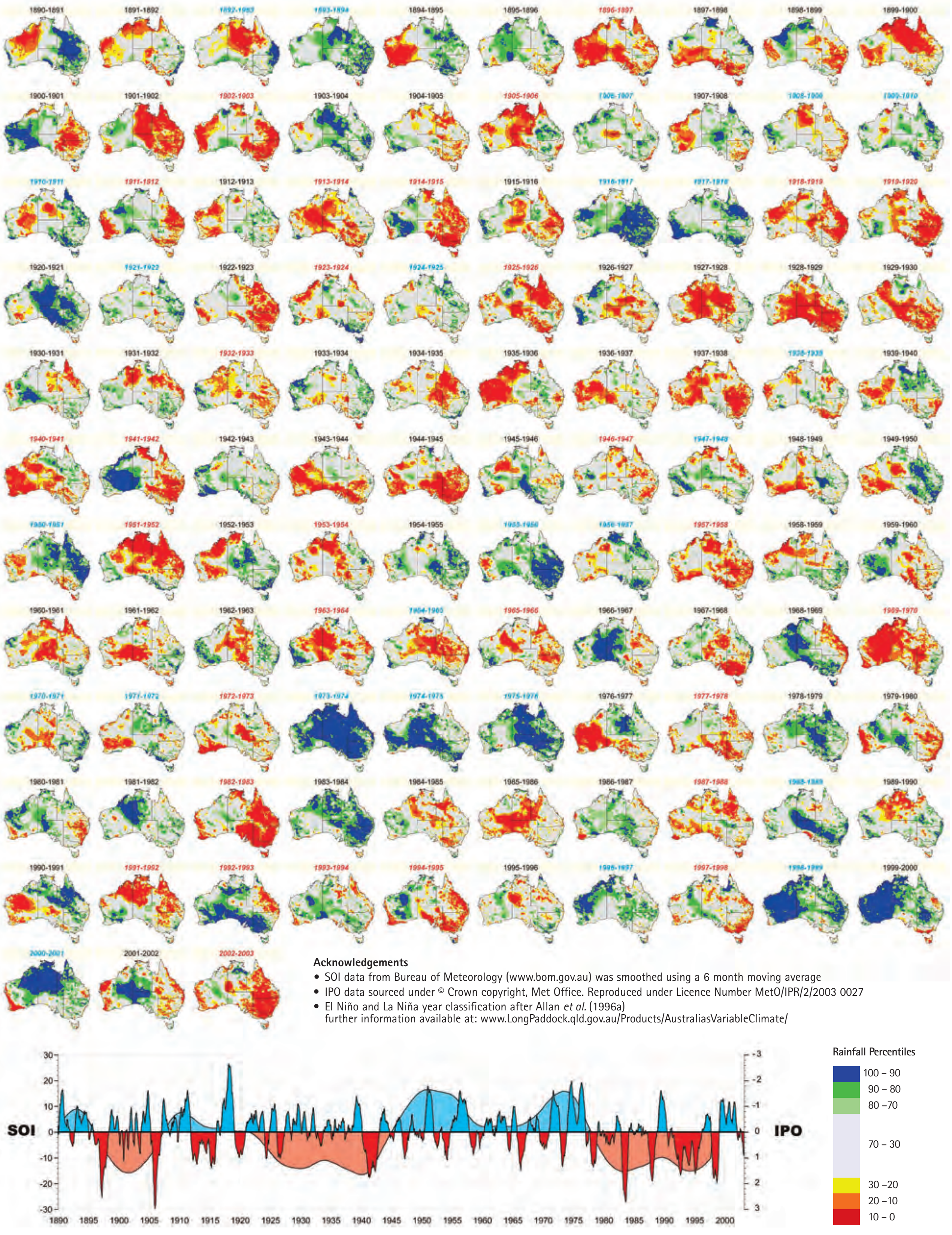
Chapter 1

Historical Degradation Episodes in Australia

Global climate and economic forces and their interaction with rangeland grazing systems

'Those who cannot remember the past are condemned to repeat it'
(Santayana 1905)

G.M. McKEON
S.J. CRIMP
G.M. CUNNINGHAM
K.A. DAY
W.B. HALL
B.K. HENRY
G.H. McTAINSH
D.M. ORR
J.S. OWENS
S.B. POWER
G.S. STONE
J.I. SYKTUS
D.G. WILCOX



Acknowledgements

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- El Niño and La Niña year classification after Allan *et al.* (1996a)
  further information available at: www.LongPaddock.qld.gov.au/Products/AustraliasVariableClimate/

Plate 1.1 Australia's Variable Rainfall: April to March annual rainfall (percentiles) relative to historical records 1890–2003. Years have been classified as El Niño (red year label) or La Niña (blue year label) based on the Southern Oscillation Index (SOI, jagged line) averaged June to November (see Chapter 1.2.1 and Plate 1.3). The Inter-decadal Pacific Oscillation (IPO, smooth line) is a longer-term Pacific Ocean signal of climate variability (see Chapter 1.2.2, Figure 1.3). A wall poster version of this page is also available. Details: www.LongPaddock.qld.gov.au, email rouseabout@nrm.qld.gov.au, or contact Queensland Department of Natural Resources, Mines and Energy.

1.1 Introduction

This project has been motivated by the proposition that Australia's grazed rangelands will be better managed for future climatic variability (and climate change) by better understanding the mistakes and successes of the past. By so doing we may avoid the criticism, attributed to G.W.F. Hegel, that 'we can learn from history that we do not learn from history' (Green 1984).

This report is not intended as a history of land and pasture degradation in Australia's rangelands. Historical analyses of particular regions (e.g. Heathcote 1965, Williams and Oxley 1979, Drysdale 1995) have already been written, and are continuing to be written by authors with first-hand experience (e.g. Condon 2002), and/or access to primary sources such as property records (e.g. Bowen 1987, Oxley 1987a, 1987b; Pickard 1990, Noble 1997a). In this report we seek to derive from these existing histories the insight necessary to plan for future climatic variability and change.

The rangelands of semi-arid Australia, sometimes referred to as 'natural grazing lands', are characterised by high year-to-year variability in rainfall (Plate 1.1, Gibbs and Maher 1967). This, in turn, results in high variability in: (1) plant growth; (2) provision of nutrition for cattle, sheep and other herbivores (e.g. goats, rabbits, macropods); and (3) the capability to carry out necessary pasture management options such as fire management (Johnston *et al.* 2000). Substantial variability occurs in rainfall at longer timescales (5–30 years, Figure 1.1). Management decisions are made against a background of high variability in climate and prices received for products. The climatic extremes and/or inappropriate management have resulted in degradation episodes. Our goal in examining historical degradation episodes is to evaluate the interactions of variability in rainfall, stock numbers, native and feral herbivores, management decisions and government policy.

Because of the importance of rural industries to Australia's economy and community, the impact of climatic variability on Australian culture and society since European settlement has been well documented (e.g. Mackellar 1908, Bean 1910, Heathcote 1973, 1994). Degradation episodes have been reported by the media in terms of dust storms, floods, animal losses, financial hardship and human suffering. They have been documented formally in Royal Commissions and other reports to government (McTainsh and Boughton 1993).

The Macquarie Dictionary (1997) states that the term 'degradation', in physical geography, refers directly to the process of soil erosion resulting in the removal of material. However, the grazing system is composed of more than just soils, e.g. vegetation, animals, products, money, humans, societies and governments. In this report, whilst recognising the difficulty in application of the term to other attributes of the grazing system, we have used the word 'degradation' in the general sense of referring to the reduction in the 'character' and 'quality' (The Macquarie Dictionary 1997) of the soil, vegetation and landscapes.

Pickup and Stafford Smith (1993, p. 472), in their review of approaches to assessing sustainability in arid Australia have defined sustainable pastoral land use as:

> commercial livestock production activities on rangelands which, as a minimum, seek to:
>
> a. maintain the long term capacity of the biological system to produce forage from rainfall (although the composition of that forage may change, as may the short term capacity);
>
> b. produce an acceptable financial and non-financial return for the manager and dependants thereby providing an acceptable standard of living (this standard is a matter of preference and may include intangibles such as preferred lifestyle).

In this context the drought/degradation episodes have clearly endangered sustainable land use by placing the future productivity of the resource and viability of enterprises at risk.

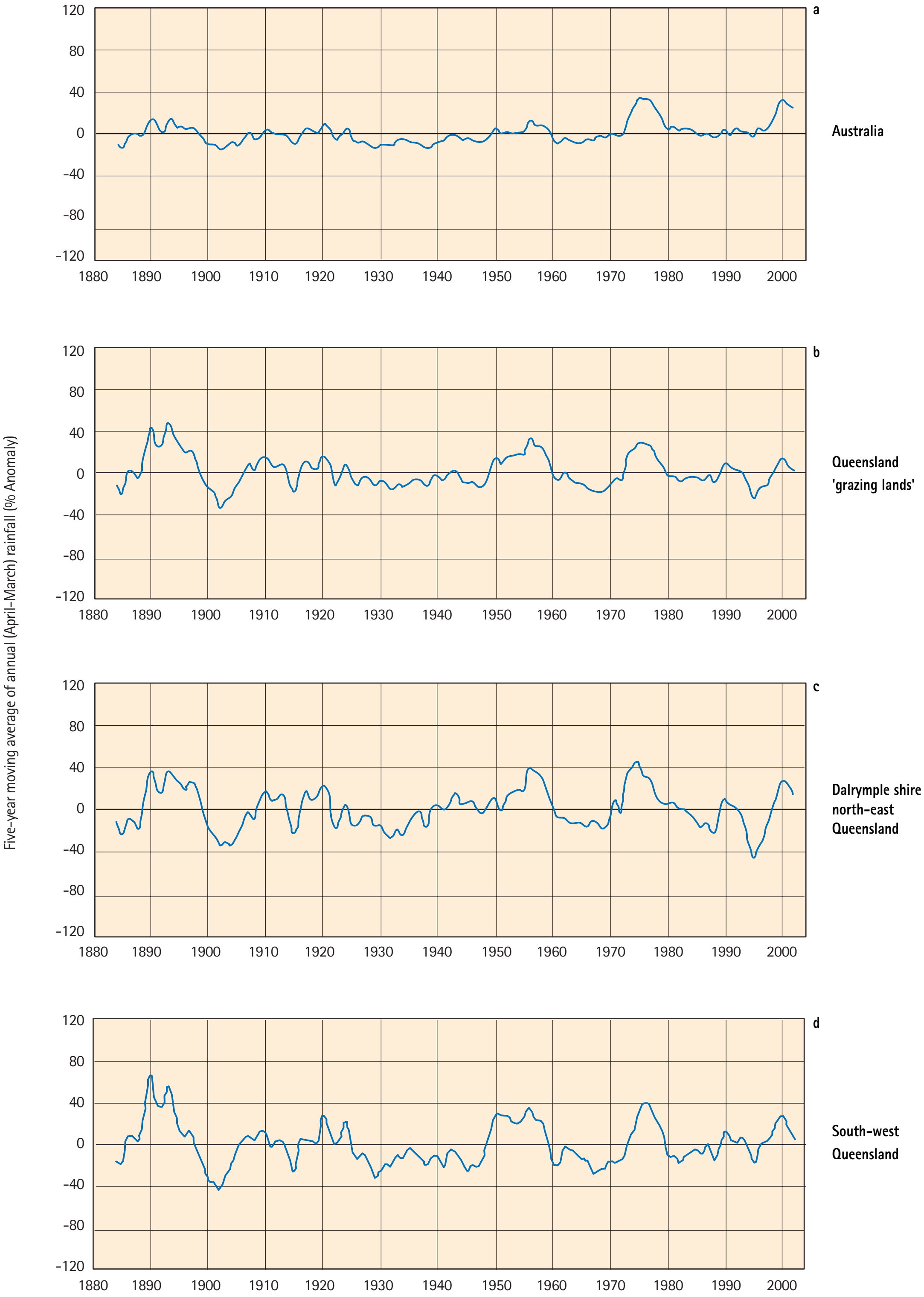


Fig.1.1 Time series of 5-year moving average of annual (April – March) rainfall (% Anomaly) for Australia and for selected regions of Australia's rangelands (Plate 1.2): a) Australia; b) spatially averaged for Queensland's grazing/cropping lands (south of 19° latitude and east of a line approximately from Cloncurry to Hungerford); c) Dalrymple shire (north-east Queensland); and d) South-west Queensland (Quilpie, Paroo and Murweh shires).

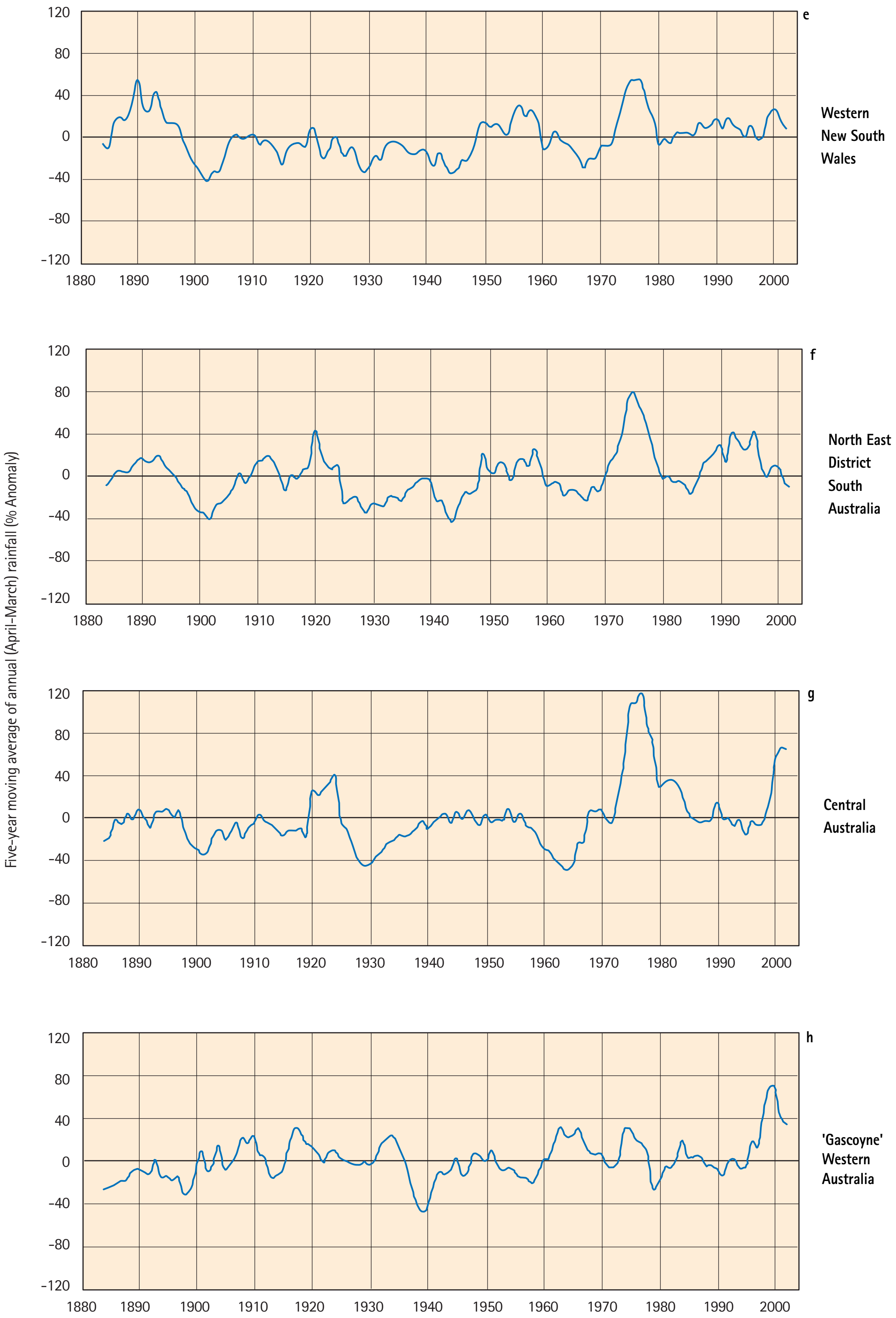


Fig.1.1 (continued) Time series of 5-year moving average of annual (April – March) rainfall (% Anomaly) for selected regions of Australia's rangelands (Plate 1.2): e) Western New South Wales: f) North East District, South Australia; g) Central Australia; and h) 'Gascoyne' region, Western Australia.

In their qualitative survey Tothill and Gillies (1992, pp. 1–2) clearly differentiated between the pasture conditions of 'deteriorating', which was perceived to be reversible, and 'degraded', which was judged to be not economically reversible:

> *Sustainability* is the long-term maintenance of the livestock production resources and environment to enable viable livestock production. *Degradation* represents an undesirable change from sustainability, and is considered at two levels ....
>
> ...either *deteriorating* – a state able to be reversed – or *degraded* – a state probably not reversible by property management.
>
> Thus '*deteriorating*' is considered to be readily reversible through improved property management and following a return to years of average or above-average rainfall; the second state is referred to as '*degraded*', where the system can only be brought back to an acceptable steady state with difficulty. This recovery is generally outside the bounds of economic management, or it cannot be done at all.
>
> There will always be periods of deterioration of the production resources resulting from seasonal and unpredictable annual fluctuations of climate. Differing levels of resilience in the resource to perturbations in different systems lead to different manifestations of system instability.

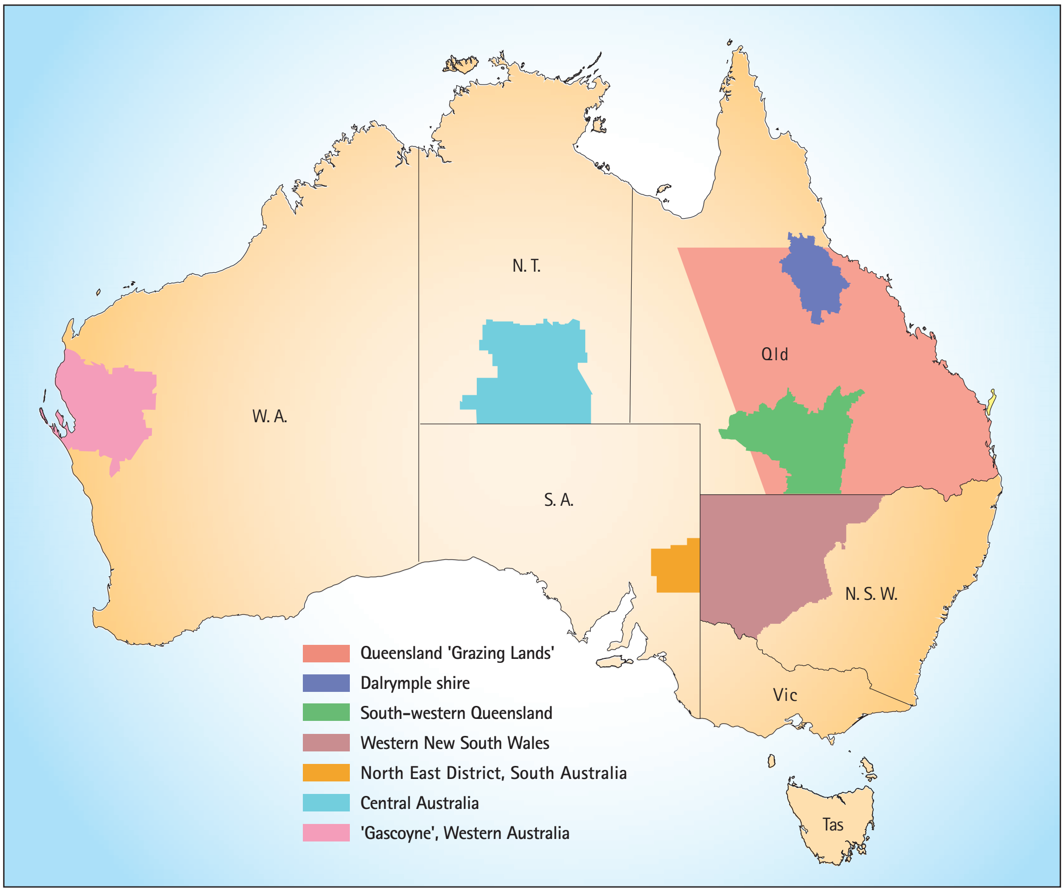


Plate 1.2 Grazing regions where the degradation and recovery episodes documented in this report have occurred: Western New South Wales – Episodes 1, 2, 4 and 5; North East District, South Australia – Episode 2; 'Gascoyne' region of Western Australia – Episode 3; Central Australia – Episode 6; South-western Queensland – Episode 7; and Dalrymple shire of Queensland – Episode 8. Queensland 'grazing lands' represents the major pastoral and cropping lands of Queensland supporting 80% of livestock grazed (south of 19° latitude and east of a line from approximately Cloncurry to Hungerford). The 'Gascoyne' region shown includes Local Government Areas of Upper Gascoyne, Murchison, Carnarvon and Shark Bay. The 'North East District' represents the North East Pastoral Soil Conservation District of South Australia.

We recognise that caution has to be exercised in use of these terms. 'Deteriorating' implies that the problem is still happening although change cannot be assessed from a single observation. Qualitative assessment of condition, especially during drought, can overestimate irreversible damage. For example, sites classified as degraded have been documented as reverting to good pasture condition (e.g. Cunningham 1996). We argue that the definitive discrimination in terms of 'reversible' and 'non-reversible' is apparent only with the benefit of hindsight. Rigid attempts to define 'degradation' obscure the fact that degradation and the associated loss of productivity occur on timescales from years to centuries.

Deterioration and degradation both describe a more fundamental change in the rangelands, namely a loss of landscape function (Ludwig *et al.* 1997). Deteriorated and degraded pasture environments are characterised by a reduced capacity to absorb rainfall and increased runoff, greater surface disturbance and greater patchiness, loss of surface soil nutrients and overall poorer nutrient availability. A precautionary approach would lead to the view that any observed degradation indicates that the resource is not being sustainably managed. Hence, in this report we have used the term 'degradation' in the general sense to embrace both the reversible and non-reversible aspects of resource damage.

The economic and ecological sustainability of Australia's rangelands was reviewed by Wilcox and Cunningham (1994). We quote their evaluation directly (p. 89):

> It was not possible to reach definite conclusions concerning the ecological sustainability of present pastoral practices. It is known that past use of the land for pastoral purposes has degraded it so that it no longer produces at its potential. In some states it is thought that some of the degradation, as much as 4 to 5 per cent, is irreversible. The state of the remaining land may be rectified by adjustments to stocking practices or by the introduction of fire and other agents of change. As monitoring systems have been introduced only in the last decade there is no objective evidence on the influence of present management except for a small area in Western Australia where the condition of most sites has improved, although a small proportion continues to decline.

1.1.1 Degradation episodes and climate variability

During the last hundred years the following eight degradation episodes have achieved some level of public and political notoriety:

1. 1890s in western New South Wales involving soil erosion, the impact of woody weed infestation, rabbit plagues, substantial financial losses and financial hardship, and resulting in the Royal Commission of 1901 (Anon. 1901, Bean 1910);

2. 1920s-30s in South Australia and western New South Wales involving substantial loss of perennial vegetation and soil erosion (Ratcliffe 1936, 1937) resulting in government legislation for regulation of carrying capacity (Donovan 1995);

3. 1930s in the Gascoyne region of Western Australia involving substantial loss of perennial shrubs, soil erosion and animal losses documented in the Royal Commission of 1940 (Fyfe 1940, Wilcox and McKinnon 1972) and subsequent enquiries (Jennings *et al.* 1979, Pastoral Wool Industry Task Force 1993);

4. 1940s in western New South Wales involving substantial dust storms and animal losses graphically portrayed in Russell Drysdale's paintings and Keith Newman's newspaper reports (Condon 2002) and supporting the need for government action (Beadle 1948);

5. 1950s in western New South Wales involving large increases in woody weeds resulting in reduced carrying capacity and income especially during a subsequent drought period (Anon. 1969, Hodgkinson *et al.* 1984);

6. 1960s in central Australia involving wind and water erosion resulting in extensive surveys and re-assessment of carrying capacity (Chippendale 1963, Condon *et al.* 1969a, 1969b, 1969c, 1969d, Purvis 1986);

7. 1960s – 70s in south-west Queensland involving soil erosion and woody weed invasion resulting in the government-sponsored South-West Strategy supporting review of recommended carrying capacities and property amalgamation (Warrego Graziers Association 1988, Johnston *et al.* 1996a, 1996b); and
8. 1980s in north-east Queensland involving erosion and loss of 'desirable' perennial grasses, resulting in extensive government-sponsored surveys (e.g. De Corte *et al.* 1994, Rogers *et al.* 1999) and dramatic grazier response (Landsberg *et al.* 1998, Anon. 1999).

The term 'degradation' can be over-used. However, in the above cases the first-hand observers appeared to be in no doubt as to the severity of damage occurring to the landscape and vegetation. The subsequent recovery of vegetation, as has occurred in some cases, is discussed later in this chapter. In Chapter 2 each episode is assessed in terms of the phases of both 'degradation' and 'recovery'.

Other examples of degradation (and partial recovery) involving grazing, which we have not been able to document to the same extent as the eight above, include:

1. woody weed infestation on the western slopes and plains of New South Wales with pine scrub in 1870s and 1880s (Rolls 1981, R.W. Condon pers. comm.);
2. probable resource damage in southern districts of the Western Division of New South Wales before the late 1880s (e.g. Condon and Stannard 1956);
3. waves of woody weed infestation in western New South Wales following various runs of wet years such as 1973-1976 (Rolls 1981, R.W. Condon pers. comm.);
4. pasture composition change involving the replacement of kangaroo grass (*Themeda triandra*) by black speargrass (*Heteropogon contortus*), contributing to the loss of sheep/wool production in south-east Queensland in the 1870s (Shaw 1957, Bisset 1962, Mott *et al.* 1992);
5. concern regarding damage to Mitchell grasslands in the extended droughts of the late 1920s and early 1930s (White 1935, Everist 1935);
6. severe and extensive degradation around permanent waters in the Gawler Ranges, South Australia in the late 1890s to 1904 (Tynan 1995);
7. pasture degradation and erosion in the early 1900s in the Kimberley (Sullivan and Kraatz 2001);
8. invasion of the exotic woody weed, prickly acacia (*Acacia nilotica*), in the 1970s in the Mitchell grasslands of western Queensland (Carter 1994); and
9. woodland thickening following changes in the fire regime from regular and frequent burning to active fire suppression following the introduction of domestic livestock (Burrows *et al.* 2002).

Newman and Condon (1969) suggested that the first degradation event in each region occurred in the first major drought after the initial increase of stock numbers in the pastoral areas. However, because of the early nature of some of these episodes, there are insufficient records of regional stock numbers or climate data for detailed analysis.

Whilst the effects of the above episodes occurred mainly during drought periods (Figure 1.1), the causes of degradation are to be found in the earlier social and environmental conditions of climate, economics, grazier perceptions and government policy, especially those policies regarding land tenure and closer settlement during the development of the pastoral industry (Cunningham 1974). Thus our approach in documenting these and other episodes is to first document the global climate and economic forces that influenced grazing enterprises over the last hundred years.

Sequences of dry or wet years have been the major climatic force in the above degradation episodes. Figure 1.1 shows the time series of five-year moving average rainfall (expressed as a percentage anomaly from the mean) for the different grazing regions of Australia where the degradation episodes occurred (Plate 1.2). Australia, as a whole, had major peaks in rainfall during the early 1890s, 1970s and the late 1990s when above-average rainfall occurred in both eastern and western Australia. For the grazing regions discussed in this report, the peaks in rainfall were more pronounced for the early 1890s, the late 1910s, the early 1920s, 1950s, 1970s and the late 1990s. These periods of above-average rainfall were most pronounced in eastern Australian grazing districts. For central Australia the main peaks occurred in the early 1920s, the mid 1970s and the late 1990s. For the Gascoyne the peaks in rainfall were at different times to the other regions of Australia (e.g. late 1900s, mid 1910s, early 1930s, mid 1960s).

Major drought periods occurred in the late 1890s to early 1900s, during the late 1920s, and the 1960s in eastern and central Australia. Western Queensland, north-eastern South Australia and western New South Wales also had major droughts in the 1940s. Queensland grazing districts had an important drought period in the early 1990s that was not as severe at other locations in eastern Australia or in central and western Australia. The Gascoyne had major droughts in the late 1890s, the late 1930s, the late 1950s and the late 1970s. Thus, the time series of rainfall indicate that widely separated regions in eastern Australia, and to a lesser extent central Australia have shared similar periods of high and low rainfall.

1.1.2 Components of the grazing system in Australia's rangelands

Australia's rangelands span a very wide range of environments from arid and semi-arid shrublands in southern and western Australia to tropical open woodlands in northern Australia. Grazing enterprises in these disparate environments have had a common system of production, based on a breeding nucleus of ewes and/or cows, allowing graziers some stability in year-to-year animal production whilst providing the opportunity for trading (i.e. buying and selling) and culling to improve the genetic base of the flock or herd. In the more temporally variable environments, trading has provided the flexibility to manage for climatic variability with financial and resource management benefits (Foran and Stafford Smith 1991, Stafford Smith and Foran 1992).

Breeding-based enterprises depend on a continuity of forage supply either for animal growth or maintenance. In variable climates perennial forages such as grasses and palatable shrubs provide this continuity. Their tissues and organs are long-lived (leaves and stems) or have slow rates of breakdown (especially for seeds), and allow forage supply of adequate nutritive value to continue through droughts which may last longer than one or two years. Perennial forages also provide nutritive value by responding rapidly to rainfall events that are too small for germination and establishment of annuals and/or ephemeral species. Grazing systems based on ephemerals or annuals (e.g. Flinders grass (an annual grass) and forbs in western Queensland) lack such a continuity of forage supply, and hence in the event of drought, animals have been: (1) supplemented by alternative forage sources (e.g. topfeed and browse); (2) sold or agisted; or (3) left to fend for themselves.

The perennial forage component provides stability of surface soil cover in terms of reducing soil erosion driven by wind and water. In the case of open woodlands and treeless plains, the perennial tussock grasses also provide the fuel for regular burning, which maintains the valuable grass component by reducing the woody plant density through either competition or direct death of fire-sensitive woody plants. Thus, for the major grazing lands, it is possible to identify the 'desirable' perennial forage resource (grasses and shrubs) which forms the basis for stability of forage supply and resource functioning.

During growth periods, annual and ephemeral species are usually of high nutritive value (protein and digestibility) and provide the high level of nutrition required for rapid animal growth. However, they are

short-lived with rapid organ turnover, so that after senescence their tissues usually detach and decompose rapidly, especially where moisture (dew, rainfall) and strong winds occur. Where climate conditions remain very dry, dead tissues can retain reasonable nutritional value. Hence, annual plant species can form the basis of stable grazing systems where year-to-year variation in rainfall is low. However, when severe rainfall deficiency occurs, the stability of animal enterprises and resource condition is placed at risk. Thus, it is not surprising that ecologists and resource managers concerned with sustainable grazing systems in a variable climate express a strong desire for the presence of palatable perennial species (e.g. Tothill and Gillies 1992).

Degradation, from the viewpoint of grazing value, involves the loss of productivity of this 'desirable' perennial forage component of the understorey. 'Desirable' refers to the value of the species to the grazing animal and stability of forage supply. In the different rangeland systems the 'desirable' perennial forage component occurs as perennial tussock grasses, as in the case of the open woodlands and rolling downs of northern Australia, or as perennial forage shrubs in the arid and semi-arid rangelands of Western Australia, South Australia and western New South Wales. In western New South Wales and south-west Queensland, both 'desirable' grasses and shrubs are represented. The major causes of the loss of 'desirable' perennial forage are:

1. severe and/or extended drought;
2. a combination of heavy grazing and drought;
3. selective grazing and competition with unpalatable grasses and shrubs;
4. competition from woody overstorey; and/or
5. lack of recruitment.

There are other mechanisms leading to the loss of 'desirable' perennial forage, such as pastures becoming moribund because of the absence of grazing or fire (Mitchell grass (*Astrebla* spp.) Payne and McLean 1939), and exceptionally wet conditions, disease, severe frost or pests.

The productivity of perennial forages can also be greatly reduced by soil erosion through the direct loss of soil nutrients (nitrogen and phosphorus) and loss of available moisture by increased runoff and decreased capacity to store moisture (McIvor *et al.* 1995a). For example, in some semi-arid soils (e.g. mulga lands of New South Wales and Queensland) nutrients are concentrated near the soil surface (Miles 1993) and hence the loss of a small depth of soil through erosion can result in large decreases in nutrient availability and potential productivity. The main cause of accelerated erosion is loss of cover from grazing and grazing-related soil disturbance.

The major management issue in using the rangelands has been how to manage stock numbers to maintain desirable perennial species given variability and changes in climate, commodity prices and costs of production, government policy, and technical capability. In the next sections we review in greater detail:

1. variation and changes in climate phenomena affecting Australia's rangelands over the last hundred years;
2. changes in commodity prices and technologies used in grazing industries;
3. changes in grazing pressure on the rangeland resource;
4. climatic and management-driven mechanisms of degradation including soil erosion and woody weed infestation; and
5. processes leading to resource resilience and recovery.

1.2 Changes in climate forcings from 1880 to the 1990s

Some of the year-to-year variability is the result of the 'chaotic' nature of the climate system. However, major fluctuations have also occured in the 'forces' that drive the climate system. These include natural forces such as solar variability and volcanic eruptions, and human-induced impacts such as greenhouse gas emissions from fossil fuels and land use change, stratospheric ozone depletion and sulphate aerosols (IPCC 1996, 2001). Variation in these forcings in combination with chaotic climatic processes results in a complex global climate system in which cause and effect are not easily identified (e.g. Nicholls *et al.* 1999). Nevertheless, recent studies of components of the global climate system are revealing consistent patterns in temporal and spatial variability. For example, Allan (2000, p. 3) reported that 'spectral analyses of global historical sea surface temperature (SST) and mean sea level pressure (MSLP) anomalies reveal significant climate signals at about 2–2.5, 2.5–7, 11–13, 15–20, 20–30 and 60–80 years, and a long-term secular trend'. As with any new understanding, new words or terms are being created to describe climate phenomena and we refer to further examples of these from the recent scientific literature.

Various studies have found that year-to-year variability in regional rainfall over a hundred years is composed of signals at quasi-biennial (e.g. 2.5 years), inter-annual (e.g. 3–7 years), quasi-decadal (e.g. 11–13 years) and inter-decadal (e.g. 15–20 years) timescales. The values for the different timescales vary between studies (e.g. Allan 2000, Meinke 2003, White *et al.* 2003). White *et al.* (2003) analysed variability in summer rainfall for the rangeland grazing districts in eastern and central Australia (Plate 1.2, Figure 1.1). They found that the longer period signals dominate, accounting for the 'inter-decadal quasi-periodicity of the drought/flood cycle'. Similarly, Meinke *et al.* (2003) found that 'significant modulations of annual terrestrial rainfall' were produced by the 'traditional' ENSO signal as well as 'ENSO-like phenomena operating on decadal (9–13 years) and inter-decadal (13–18 years) time scales'. Allan *et al.* (2003) suggest that it is not just the inter-decadal signals that have an impact on Australia, but that the quasi-decadal signal, through interactions with the quasi-biennial and inter-annual ENSO influences, also has an effect.

Much of this new understanding of the global climate is 'research in progress'. Thus, in this report we have considered only some of the major climate forcings affecting climatic variability in Australia's rangelands that have been well documented at the time of writing (2003):

1. the El Niño – Southern Oscillation (ENSO) (Pittock 1975, 1978);
2. the Inter-decadal Pacific Oscillation (IPO) (Power *et al.* 1999);
3. synoptic circulation systems (Pittock 1975, 1978);
4. global warming and other human-induced changes (Nicholls *et al.* 1996a, Power *et al.* 1999, IPCC 2001); and
5. unpredictable variability arising from the partially chaotic nature of the climate system (e.g. Lorenz 1976, Power *et al*. 1995, Walsh *et al.* 1999).

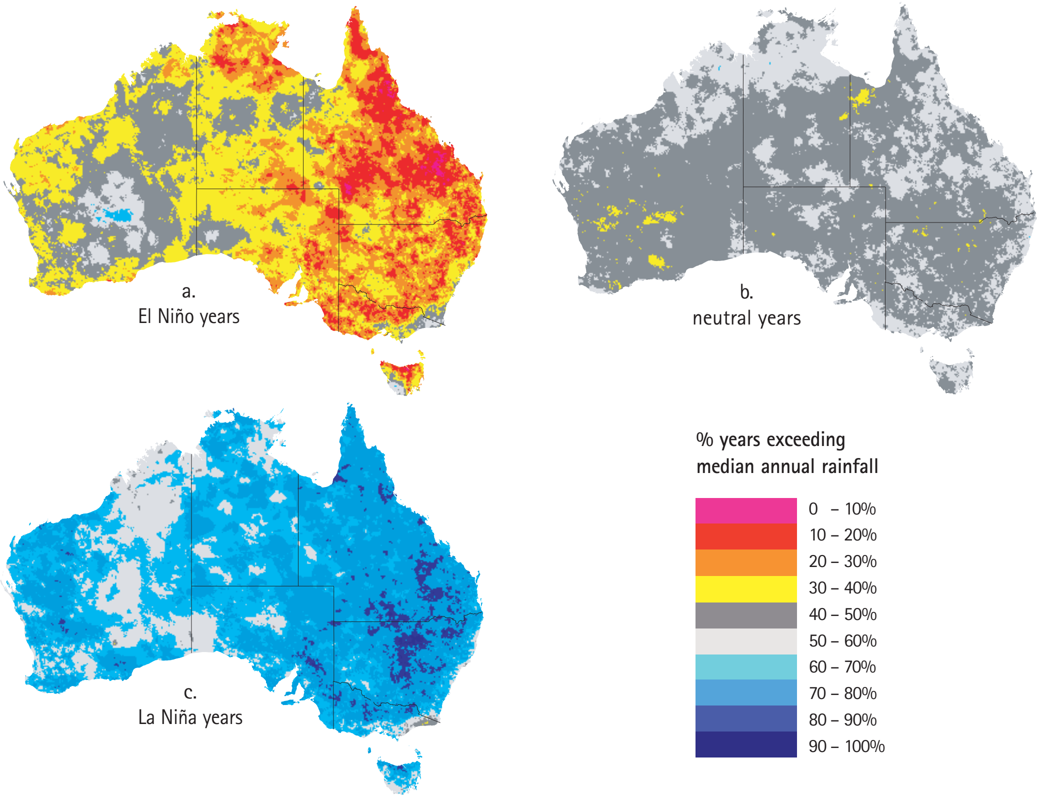
1.2.1 El Niño – Southern Oscillation

Over the past hundred years, global phenomena such as ENSO have exerted a strong influence on rainfall especially in eastern Australia (Pittock 1975, McBride and Nicholls 1983, Power *et al.* 1999) and on the biology of Australian rangelands (Taylor and Tulloch 1985). Generally 'El Niño' years (eastern Pacific anomalously warm) are associated with increased chance of below-average rainfall in contrast to 'La Niña' years (eastern Pacific anomalously cold) that have an increased chance of above-average rainfall. In the rangelands, these effects are strongest in eastern Australia, especially regions of Queensland and New South Wales (Partridge 1991).

A commonly used measure of ENSO is the Southern Oscillation Index (SOI), the normalised difference in atmospheric pressure between Tahiti and Darwin (Allan *et al.* 1996a, 1996b). Allan *et al.* (1996a) used the six-month SOI averaged from June to November as a criterion to differentiate 'El Niño' (SOI ≤–5) and 'La Niña' (SOI ≥+5) years. For the 104 years from 1891 to 1994 they identified 27 El Niño years with intervals between occurrence ranging from one to eight years. Similarly they identified 22 La Niña years with intervals between occurrence ranging from one to 14 years. We have repeated the analysis for the period 1890 to 2002 using the revised SOI available from the Bureau of Meteorology (http://www.bom.gov.au). The SOI threshold for classifying years was increased to 5.5 to match the year classification of the original analysis of Allan *et al.* (1996a).

Plate 1.3 shows the impact of ENSO on the percentage of years that have exceeded median annual rainfall (1 April to 31 March) for each of the three year-types (El Niño, neutral and La Niña) as classified above (1890 to 2002). A statistical analysis (Chi square, Plate 1.4a) indicates that the effects have been strongest in a wide range of grazing regions in eastern Australia, the 'top end' of the Northern Territory, eastern South Australia and western rangeland areas of Western Australia (e.g. Gascoyne-Murchison region). 'El Niño' years in these regions have resulted in a low (10–40) percentage of years exceeding median rainfall with central and north-eastern Queensland having the lowest percentage (10–20).

In La Niña years, there has been a high (60–90) percentage of years exceeding median rainfall over grazing regions with the highest percentage (80–90) in central New South Wales and southern Queensland. The strongest effects of ENSO on seasonal rainfall are generally in the period July to March, with timing of the effect varying considerably with location (McBride and Nicholls 1983, Coughlan 1988, Stone *et al.* 1996). Nevertheless the dominating effects on annual rainfall (1 April to 31 March) are apparent in Plate 1.3.


a.
El Niño years

b.
neutral years

c.
La Niña years

Plate 1.3 Percentage of years from 1890 to 2002 exceeding median annual rainfall (1 April to 31 March) for three year-types: a) 'El Niño'; b) 'neutral'; and c) 'La Niña' years. Years were classified based on the average June to November SOI: 'El Niño' years SOI ≤ – 5.5 (29 years); 'neutral' years – 5.5<SOI<+5.5 (59 years); and 'La Niña' years ≥+5.5 (25 years).

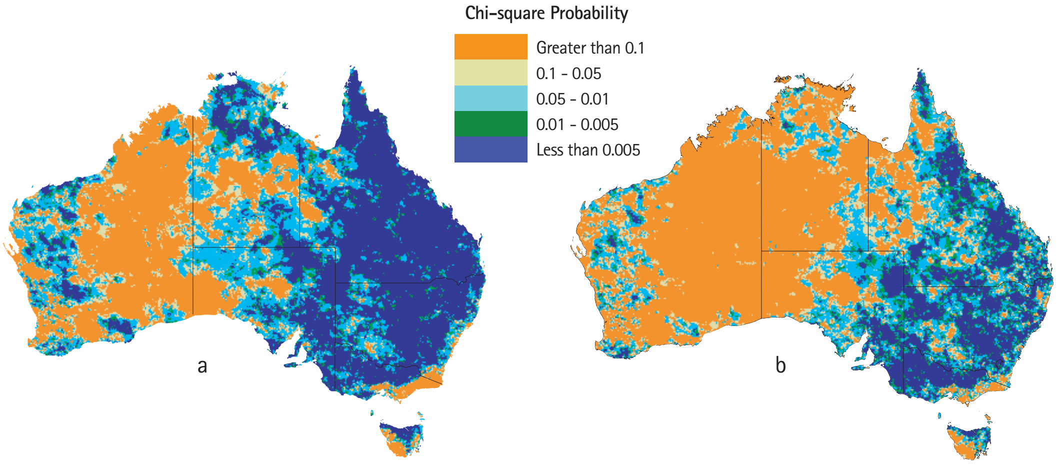


Plate 1.4 Probability of Chi-square values for: a) the classification of years into three types based on June to November SOI; (1) 'El Niño' (SOI ≤ –5.5), (2) 'neutral' (–5.5 <SOI <+5.5), and (3) 'La Niña' years (SOI ≥+5.5); and b) years classified into six year-types; (1) *SOI negative – IPO cool* (16 years), (2) *SOI negative – IPO warm* (17 years), (3) *SOI neutral – IPO cool* (17 years), (4) *SOI neutral – IPO warm* (30 years), *(5) SOI positive – IPO cool* (17 years), and (6) *SOI positive – IPO warm* (11 years) (Section 1.2.3). Probability values less than 0.05 are interpreted to indicate non-random effects.

ENSO-based forecasting systems

The persistence of SST anomalies and the coupling of atmospheric and oceanic processes have allowed seasonal forecasting systems to be developed (e.g. McBride and Nicholls 1983, Coughlin 1988, Stone *et al.* 1996, Drosdowsky and Chambers 1998). The systems confirm the importance of ENSO in affecting rainfall variability in Australia's rangelands.

A detailed analysis (Stone *et al.* 1996) of the impact of ENSO on seasonal (three-monthly) rainfall has been carried out for all locations in Australia based on SOI phases (Phase 1, SOI consistently negative; Phase 2, SOI consistently positive; Phase 3, SOI falling; Phase 4, SOI rising; and Phase 5, SOI neutral). The analysis of Stone *et al.* (1996) indicates a strong effect of ENSO across most of Australia but the size and sign of the anomaly in rainfall vary considerably with the season of influence.

Alternative forecasting systems (Nicholls *et al.* 1999) have been developed by the Bureau of Meteorology Research Centre (Drosdowsky and Chambers 1998, Drosdowsky 2002). A simplified form of this system is employed operationally in the Bureau of Meteorology's National Climate Centre using Indian and Pacific Ocean SST patterns as predictors. This system replaced an earlier forecasting system that used the SOI (lagged 3 months) as a single predictor. The extent to which Indian Ocean variability is independent of ENSO is an active research area (R.J. Allan pers. comm., N. Nicholls pers. comm.).

Statistical analysis of these forecasting systems (Drosdowsky and Chambers 1998, Nicholls *et al*. 1999) shows that they are useful in forecasting rainfall during:

1. summer in eastern coastal Australia and central Western Australia;
2. autumn in northern Australia and central and southern Western Australia;
3. winter in southern Queensland, New South Wales and south-east Australia; and
4. spring in northern Australia and some areas of eastern Australia.

In a global historical analysis of ENSO behaviour, Allan *et al.* (1996b, p. 77) identified the 20 years, 1921 to 1941, as an epoch 'in which ENSO and the climate system appear to have been functioning in a less robust manner than in recent or earlier periods over the last 120 or so years'. Similarly, behaviour of ENSO since the

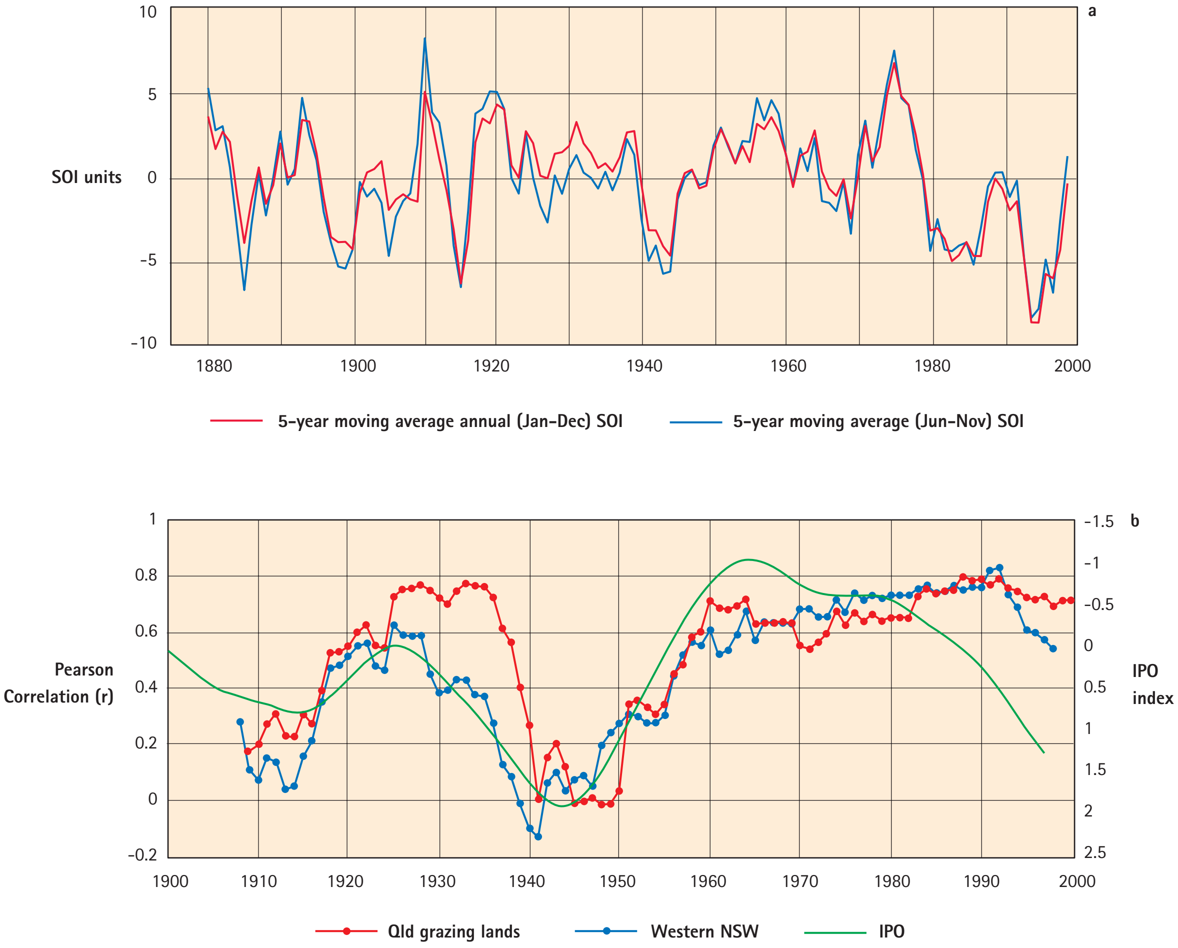


Figure 1.2 **a** Five-year moving averages of annual (January to December) SOI and winter-spring (June to November) SOI; and **b** Variation in the relationship between ENSO and rainfall as shown by the Pearson correlation coefficient (r) for 19-year moving windows of annual (April to March) SOI and annual (April to March) rainfall (cube root transformation) in Queensland's grazing lands and western New South Wales; and 19-year moving window of the IPO 'index' (refer to Section 1.2.2 and Figure 1.3).

mid 1970s has been regarded as unusual compared to the previous hundred years of record (Figure 1.2a, IPCC 1996, 2001). The correlation between rainfall and SOI (or its surrogates) has fluctuated over time (Figure 1.2b, Treloar and Grant 1953, McBride and Nicholls 1983, Nicholls *et al.* 1996b, Power *et al.* 1999). For Queensland's grazing lands (Plate 1.2) there were strong correlations from 1890 to 1920, weak correlations from about 1920 to 1950 and strong correlations since 1950 (McKeon *et al.* 1998).

Thus ENSO behaviour over the last 100 years has shown variability in frequency of El Niño and La Niña events and variability in the correlation with rainfall in regions. Allan *et al.* (1996b, p. 70) state that 'ENSO and the climate system have undergone decadal to multi-decadal "shifts", with climatic relationships and ENSO patterns fluctuating between robust and weak conditions'. Possible impacts of anthropogenic factors on the relationship between ENSO and rainfall are not yet fully understood (Section 1.3) and this is an area of active research. Nevertheless, ENSO is generally recognised as a major cause of year-to-year climatic variability especially in eastern Australia (Pittock 1975). The next sections investigate the source of variability in ENSO and its impacts.

1.2.2 Inter-decadal Pacific Ocean oscillation

With the recent compilation of long-term global data sets of oceanic and atmospheric measures, both trends and inter-decadal oscillations are emerging. Recent research (Folland *et al.* 1998, 1999, Mantua *et al.* 1997, Power *et al.* 1999, Mantua and Hare 2002) has identified that SSTs in the Pacific Ocean vacillate/oscillate on inter-decadal timescales. Two indices of historical inter-decadal variability have been reconstructed, the Inter-decadal Pacific Oscillation (IPO, Folland *et al.* 1999, Power *et al.* 1999) and the Pacific Decadal Oscillation (PDO, Mantua and Hare 2002). As described in detail later, SSTs during the phases of the IPO/PDO resemble average El Niño-like and La Niña-like patterns in the Pacific Ocean. The oscillation is associated with fluctuations in the impact that ENSO has on rainfall in Australia's grazing lands (Power *et al.* 1999). In one phase of the IPO, tropical Pacific SSTs in the eastern Pacific were anomalously cold with strong gradients to the mid-latitudes. When La Niña years occurred under these conditions, above-average rainfall also occurred in several regions of Australia's grazing lands (e.g. early 1890s, 1916/17–1917/18, mid 1950s, early/mid 1970s). Although we do not yet have a mechanistic understanding of the IPO, its behaviour appears linked to the history of rangeland degradation and recovery.

Folland *et al.* (1998, p. 1) state that 'there is increasing evidence of coherent patterns of variability on near quasi-bidecadal time scales in a range of climatic data from many parts of the world'. They investigated multi-decadal variability in observed ocean surface temperatures and found a 'quasi-El Niño pattern' in SSTs that 'extends further west into the tropical West Pacific than on ENSO time scales'. Further, they reported 'a fairly striking relationship between Southern African rainfall and large scale SST patterns since 1900' (p. 1) on quasi-bidecadal and longer timescales. Power *et al.* (1999) documented several indices of this IPO (Figure 1.3) and showed links between the IPO and decadal variability in ENSO teleconnections.

In the following analyses we have used the SST-based IPO 'index' of Power *et al.* (1999) which was 'created from the Met Office Historical Sea Surface Temperature (MOHSST6) dataset. This index is the time series of the third empirical orthogonal function (EOF3) of low-pass (> 13 year) filtered global gridded SST for 1911-1995' (Folland *et al.* 1999). We document the above technical definition to indicate that indices such as that for the IPO are derived from complex analyses of global SSTs. Hence a major challenge is to provide the indices in a form that resource managers can understand and use (e.g. Day *et al.* 2000).

Power *et al.* (1999) examined the correlations between SOI and various climate-related variables such as Australian continental rainfall, Murray River flow, Australian continental temperatures, and a climatic index of domestic wheat yield for different values of IPO index. When the IPO index was positive, correlations were weak or non-existent but when the IPO index was negative, correlations were strong (absolute values 0.4 to 0.8). The analysis of Power *et al.* (1999), whilst not providing a mechanistic understanding of the link between IPO and ENSO teleconnections, nevertheless clearly demonstrates that the varying correlations between the SOI and climatic variables such as rainfall are statistically associated with global fluctuations in SSTs on long timescales (10 to 20 years).

The naming of phases of the IPO/PDO as 'positive' and 'negative' (e.g. Figure 1.3) causes confusion because of the importance of the combinations of 'SOI positive – IPO negative' and 'SOI negative – IPO positive' for increased chance of high rainfall or drought respectively. Hence in the following analysis we have referred to the IPO/PDO negative and positive phases as *cool* and *warm* respectively. As will be discussed later, this naming convention is consistent with the average SST patterns in the eastern Pacific Ocean associated with each phase. This naming is also in agreement with the description of the PDO given by Mantua and Hare (2002, p. 35). They indicated that '"cool" PDO regimes prevailed from 1890–1924 and again from 1947–1976, while "warm" PDO regimes dominated from 1925–1946 and from 1977 through (at least) the mid 1990s'.

Other indices of inter-decadal Pacific Ocean oscillation

Mantua *et al.* (1997) and Mantua and Hare (2002) developed an index, the 'PDO, Pacific (inter) Decadal Oscillation' from tropical and northern hemisphere SSTs. The PDO index is derived as the leading principal component of monthly SST anomalies in the North Pacific Ocean, poleward of 20°N. Any global warming signal has been removed by calculating the 'difference between observed anomalies and the monthly mean global average SST anomaly'. Their PDO showed similar oscillations over time (Figure 1.3) to that presented by Power *et al.* (1999). Mantua *et al.* (1997, p. 1075) stated:

> We have identified an inter-decadal climate signal that is evident in the oceanic and atmospheric climate record. We attribute these signatures to the PDO. During this century, using the North Pacific SST pattern time series as the indicator of polarity, the PDO was predominantly positive [*warm*] between 1925 and 1946, negative [*cool*] between 1947 and 1976, and positive [*warm*] since 1977. Note that these multidecade epochs contain intervals of up to a few years in length in which the polarity of the PDO is reversed e.g., the positive [*warm*] PDO values in 1958-61, and the strongly negative [*cool*] PDO values in 1989-91.

The IPO and PDO are two indices of inter-decadal variation in the Pacific Ocean with similar historical patterns of change (Figure 1.3). Folland *et al.* (2002) examined the influence of the IPO and ENSO on the South Pacific Convergence Zone (SPCZ), a region of importance for eastern Australian rainfall (Day *et al.* 2000, Crimp and Day 2003). Folland *et al.* (2002) commented on the relationship between PDO and IPO indices:

> The IPO pattern is quasi-symmetric about the meteorological equator near 5°N and its North Pacific manifestation is similar to that of the Pacific Decadal Oscillation (PDO) (Mantua *et al.* 1997) described for the North Pacific only. Because the IPO is defined for the whole Pacific Basin, we use it in preference to the PDO.

They summarised their findings as follows:

> Our study demonstrates the equivalence of the IPO and PDO in describing Pacific-wide variations in ocean climate, and has defined a station-pressure-based index capable of tracking the IPO through the 20th century. It also has demonstrated that both ENSO and the IPO influence the SPCZ quasi-independently. Spatial patterns of decadal trends in recent climate in the South Pacific are strongly affected by the SPCZ, especially the changes in the mid 1970s (Folland *et al.*, 1997; Salinger *et al.*, 1995). Small displacements in the mean position of the SPCZ are important for South Pacific climates. Finally, interactions of the SPCZ with features like the IPO may have far wider hemispheric climatic impacts, given the importance of the SPCZ to both tropical and Southern Hemisphere general atmospheric circulation.

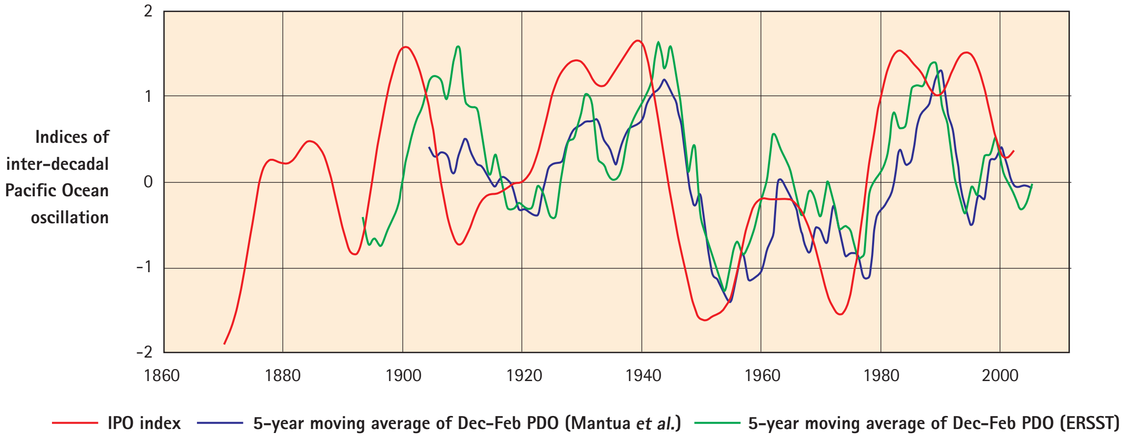


Figure 1.3 Several measures of inter-decadal variability in Pacific Ocean SSTs: (1) IPO 'filtered' index from the UK Meteorological Office; (2) 5-year moving average of Dec.-Feb. PDO described by Mantua *et al.* (1997) and Zhang *et al.* (1997); and (3) 5-year moving average of Dec.-Feb. PDO based on extended reconstructed sea surface temperature (ERSST) (Smith and Reynolds 2003). The IPO index was used by Power *et al.* (1999) in their analysis.

Mantua *et al.* (1997) cited the supporting work of Minobe (1997) who carried out a complementary study identifying similar dates for 'climate regime shifts' and suggesting 'PDO-like climate variability' with a 'recurrence interval of 50–70 years' and fluctuations 'evident throughout the past 3 centuries'. Mantua *et al.* (1997) reviewed the implications of inter-decadal climate patterns for impacts on salmon production in the northern Pacific. Their PDO index shows short periods of changing polarity, e.g. 1989 to 1991, that were not followed by sustained 'long-lived' regime shifts. They highlighted that such conclusions were drawn with the 'benefit of hindsight' and indicated that there are problems for the operational use of the index for long-term resource (fisheries) management Nevertheless they recommended that the understanding that the climate system can exist in different regimes for relatively long periods should be used to prevent over-exploitation of fish stocks.

The various signals operating at different timescales in the Pacific Ocean SSTs are yet to be unravelled to the extent that they can be used operationally especially at an inter-decadal planning timescale (Mantua and Hare 2002). For example the 'phase' of the IPO for the late 1990s has been recalculated with updated SST information during the early 2000s. Various approaches for operational use have been proposed and are currently being tested experimentally (e.g. Day *et al.* 2000, Crimp and Day 2003, White *et al.* 2003). The following historical analyses highlight the need for further understanding to provide 'forecasts' or 'climate risk assessments' at longer timescales than current operational seasonal forecasting systems.

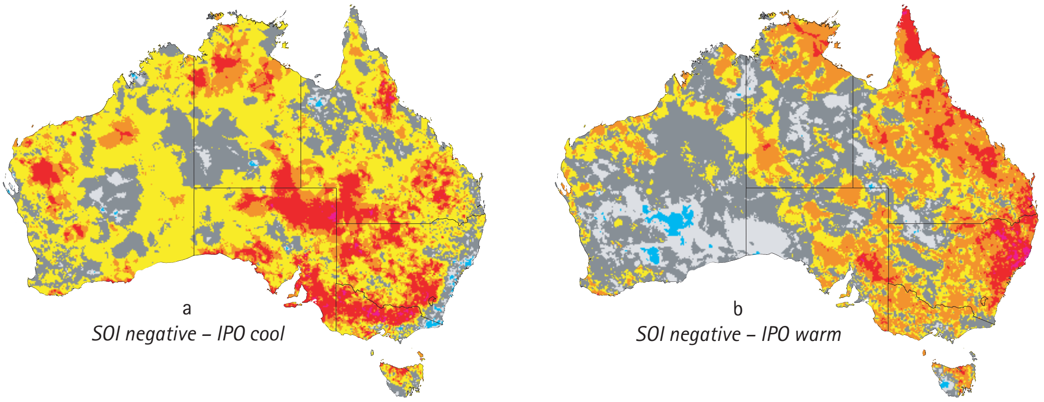
1.2.3 ENSO and IPO effects in Australia's rangelands

The influence of the association between ENSO and IPO on rainfall (Plate 1.5) and other variables was examined based on classification of each year in the 108–year period 1890/91 to 1997/98 using SOI and IPO 'index' values following the work of Allan *et al.* (1996a) and Power *et al.* (1999). Years were classified, based on the SOI averaged for June to November, into three categories: *SOI negative* (SOI ≤–4); *SOI neutral* (–4<SOI<+4); *SOI positive* (SOI ≥+4). When separated on whether the IPO 'index' was *warm* or *cool*, the following six year-types resulted:

SOI negative – IPO cool (16 years);
SOI neutral – IPO cool (17 years);
SOI positive – IPO cool (17 years);
SOI negative – IPO warm (17 years);
SOI neutral – IPO warm (30 years); and
SOI positive – IPO warm (11 years).

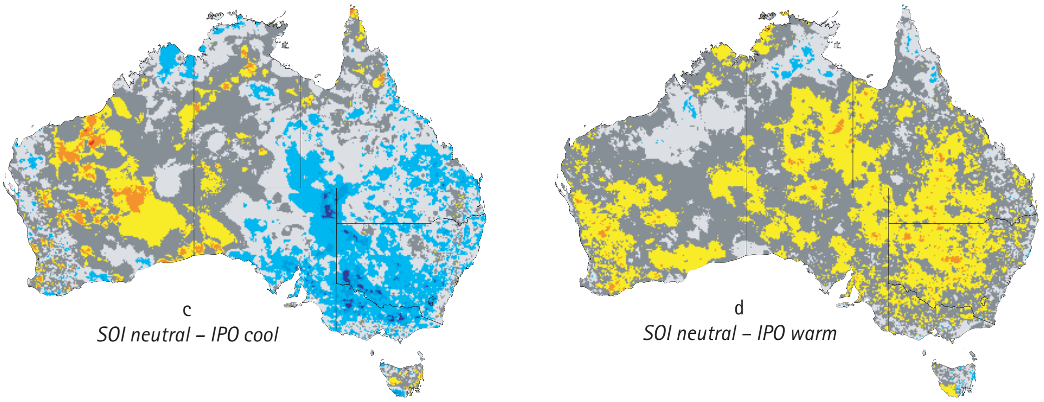
We have used '4' as the SOI threshold in this study (in contrast to '5.5' in previous analyses) to include more marginal *'SOI negative'* and *'SOI positive'* years (an additional ten years) and provide sufficient numbers of years for analysis of the smallest group (*SOI positive – IPO warm,* 11 years). Because of the inclusion of more marginal SOI extremes the following analysis provides a more conservative view of the impact of the interaction of the IPO and SOI indices compared to analyses based on groups classified on an SOI threshold of 5.5. Nevertheless the groups of *SOI negative* and *SOI positive* years are strongly dominated by El Niño and La Niña years described above. The uneven distribution in number of years is likely to be the result of *SOI positive* years and *IPO cool* years having similar patterns of SST in the Pacific Ocean as described below (Mantua *et al.* 1997).

Plates 1.6 and 1.7 show SST anomalies for the different year-types as described above. The composites (Plates 1.6a and c) of *SOI negative* and *SOI positive* show a wedge shape of warm or cold anomalies, respectively, in the central and eastern Pacific Ocean. Opposite temperature anomalies occur in the North Pacific around the dateline and in the South Pacific, north-east of New Zealand. The composites for all the *IPO cool* (Plate 1.6e) and *IPO warm* (Plate 1.6d) years show similar features to *SOI positive* and *negative* composites, respectively. For IPO composites the anomalies were not as great, nor were the wedge shapes as pronounced. Anomalies also occur in the Indian Ocean with similar sign to the eastern Pacific Ocean. When the interactions of SOI



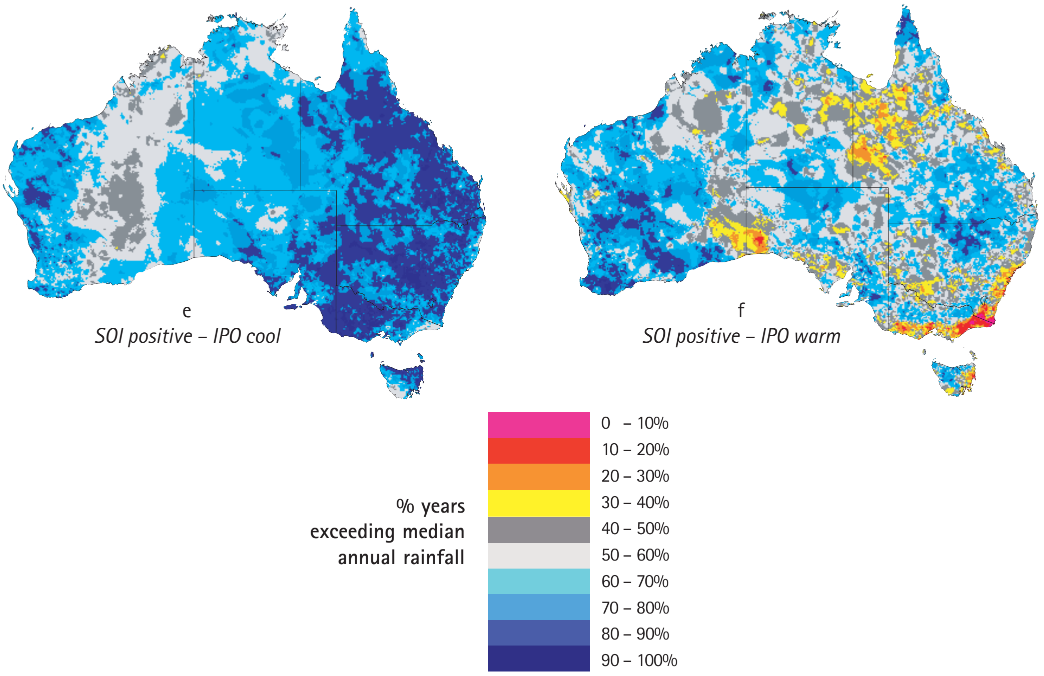
a
SOI negative – IPO cool

b
SOI negative – IPO warm



c
SOI neutral – IPO cool

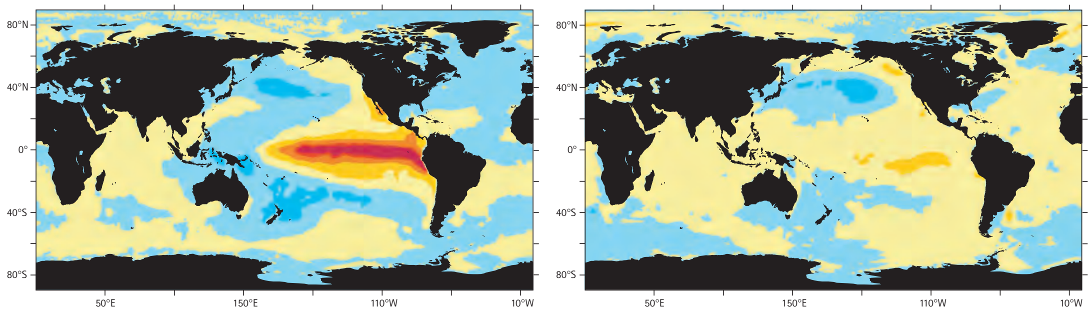
d
SOI neutral – IPO warm



e
SOI positive – IPO cool

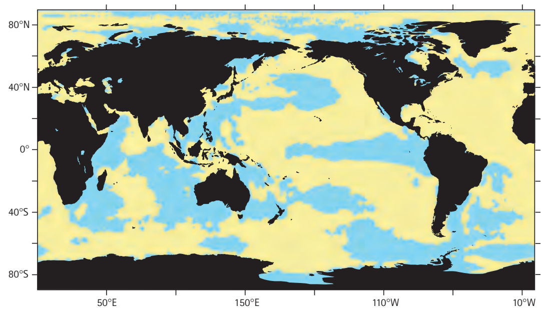
f
SOI positive – IPO warm

Plate 1.5 Percentage of years exceeding median rainfall (1 April to 31 March) for six year-types: (a) *SOI negative – IPO cool* (16 years); (b) *SOI negative – IPO warm* (17 years); (c) *SOI neutral – IPO cool* (17 years); (d) *SOI neutral – IPO warm* (30 years); (e) *SOI positive – IPO cool* (17 years); and (f) *SOI positive – IPO warm* (11 years). Years from 1890 to 1997 were initially classified into three categories based on the SOI averaged for June to Nov: *SOI negative* (SOI ≤–4); *SOI neutral* (–4< SOI <+4); and *SOI positive* (SOI ≥+4). The categories were then separated on whether the IPO 'index' was *warm* or *cool*, resulting in six year-types.



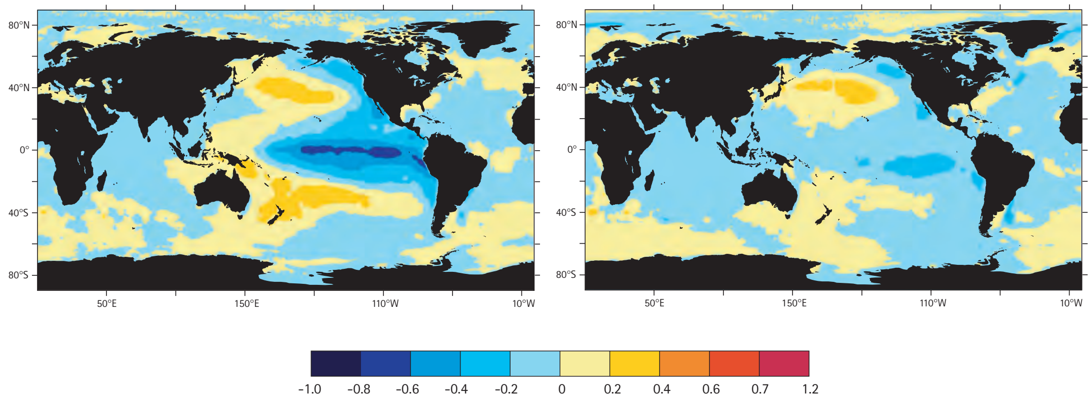
a *SOI negative*

d *IPO warm*



b *SOI neutral*

Plate 1.6 Sea surface temperature anomalies for composites of year-types: (a) *SOI* negative; (b) *SOI* neutral; (c) *SOI* positive; (d) *IPO warm*; and (e) *IPO cool*.The SOI was averaged for June to November and divided into three categories: *SOI negative* (SOI ≤–4); *SOI neutral* (–4< SOI <+4); and *SOI positive* (SOI ≥ +4).

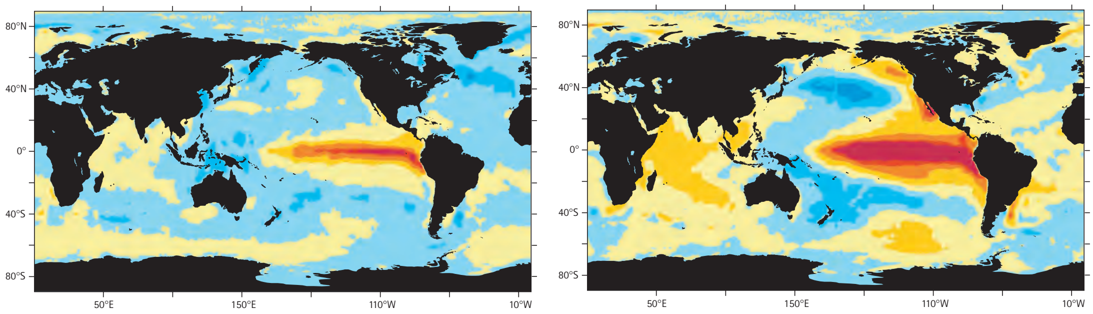


c *SOI positive*

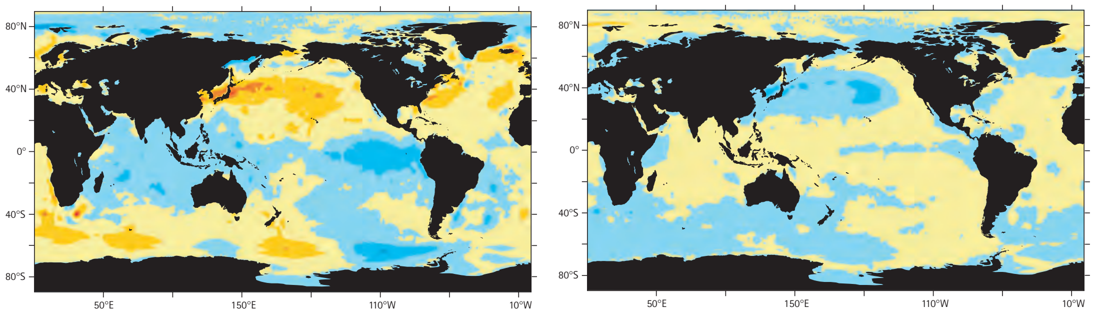
e *IPO cool*

and IPO were considered (Plate 1.7), the combination of *SOI positive* – *IPO cool* (Plate 1.7e) and SOI *negative* – *IPO warm* (Plate 1.7b) had greater SST anomalies and gradients. In the other combinations the anomaly and gradient features are smaller and concentrated on the eastern Pacific equator. For the *SOI neutral* years the *IPO warm* years (Plate 1.7d) show a mainly warmer El Niño-like wedge across much of the Pacific. In contrast, the *SOI neutral* – *IPO cool* years (Plate 1.7c) show a La Niña-like pattern in the equatorial eastern Pacific.

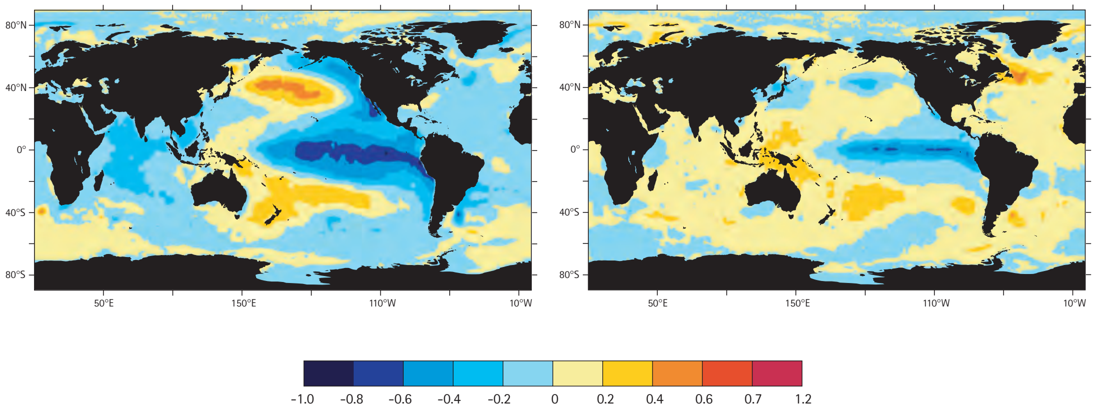
For *SOI positive* – *IPO cool* (17 years) there has been a high percentage of years (60– 90) exceeding median rainfall in both eastern and western Australia (Plate 1.5e). In this year-type, there have been widespread areas in eastern Australia with a very high percentage of years (>80) exceeding median rainfall. In contrast, the smaller group *SOI positive* – *IPO warm* (11 years) has had a lower percentage of years exceeding median rainfall in eastern Australia but higher percentages in the southern inland regions of Western Australia (plate 1.5f).


a *SOI negative – IPO cool*

b *SOI negative – IPO warm*


c *SOI neutral – IPO cool*

d *SOI neutral – IPO warm*


e *SOI positive – IPO cool*

f *SOI positive – IPO warm*

Plate 1.7 Sea surface temperature anomalies for composites of year-types: (a) *SOI negative – IPO cool* (16 years); (b) *SOI negative – IPO warm* (17 years); (c) *SOI neutral – IPO cool* (17 years); (d) *SOI neutral – IPO warm* (30 years); (e), *SOI positive – IPO cool* (17 years); and (f) *SOI positive – IPO warm* (11 years). Years from 1890 to 1997 were initially classified into three categories based on the SOI averaged for June to Nov.: *SOI negative* (SOI ≤–4); *SOI neutral* (–4< SOI <+4); and *SOI positive* (SOI ≥ +4). The categories were then separated on whether the IPO 'index' was *warm* or *cool*, resulting in six year-types.

For *SOI negative – IPO cool* (16 years) there has been a low percentage of years (<10–30) exceeding median across most of Australia, with very low percentages (<20) in western Queensland. For *SOI negative – IPO warm* coastal Queensland and New South Wales have had a very low percentage of years exceeding median rainfall.

In *SOI neutral* years the difference between IPO groups was not as large. Nevertheless, the group *SOI neutral – IPO cool* (17 years) has had 60–70% of years exceeding median rainfall in substantial areas of eastern Australia. In the large group *SOI neutral – IPO warm* (30 years) there has been a lower percentage (30 – 40) across much of western New South Wales and south-western Queensland.

The combined effect of ENSO and IPO on rainfall and simulated pasture growth (as described in Chapter 2) was evaluated for nine locations associated with the degradation episodes listed above (Tables 1.1 and 1.2).

For locations in each rangeland region the associated patterns of annual rainfall (April to March) and simulated pasture variables (pasture growth index; percent of year with days suitable for growth; native pasture growth) are similar, supporting the apparent widespread effect of ENSO and IPO associations in eastern Australia. There were greater differences between year-types for pasture growth than for rainfall. Averaged across locations (refer to footnote Table 1.2), the *SOI positive – IPO cool* years exhibited a 30–40% increase in rainfall with about 80% of years above median, no decile 1 (lowest 10%) years, and few years less than decile 3 (lowest 30%). The *SOI positive* effect was not very strong when the IPO was *warm*. In the case of *SOI negative* years, reduction in average rainfall and pasture attributes occurred for both polarities of the IPO although there was a generally stronger effect of *SOI negative* when accompanied by *warm* IPO index conditions in terms of increased drought risk (decile 1 or decile 3).

For *SOI neutral years, cool* IPO index was associated with slightly wetter conditions (approx. +10% on average) whilst *warm* IPO index was associated with drier conditions (approx. –10% on average). The worst years on record for rainfall and pasture attributes were generally associated with IPO index *warm* conditions. *SOI negative* years were not necessarily the worst on record although unequal representation of year-type limits the analysis.

The variability of rainfall is amplified in the rangelands in terms of pasture growth. For example decile 3 rainfall was on average 74% of the long-term mean while decile 3 pasture growth was only 60% of the mean. Thus in 30% of years, pasture growth was less than 60% of average expectations and worst years were very low, e.g. 5% of average. This effect was not as apparent for simulated variables such as an integrated pasture growth index (Fitzpatrick and Nix 1970) and length of the growing season (% days growth index exceeds a threshold for maintaining nutritional material) (Hall *et al.* 1998).

Multiple regression analyses combining various Pacific Ocean indices of ENSO and inter-decadal signals in the Pacific Ocean (e.g. IPO/PDO) account for 20–40% of the year-to-year variability in rainfall in the regions of major influence (e.g. in Queensland, Day *et al.* 2000, Crimp and Day 2003). As indicated above, current research is examining how other components of the climate system at different timescales can add to the explanation of year-to-year variability in Australia's rangelands (e.g. White *et al.* 2003).

Impact of ENSO and IPO on extended drought in degradation episodes

Table 1.3 shows the association between ENSO and the extended drought periods during the major degradation episodes. The extended drought periods were calculated using regional rainfall (Figure 1.1, Plate 1.2) and a standard 12–month period from 1 April to 31 March as a compromise between summer and winter rainfall regions. This period also provided closer alignment with average ENSO seasonal development than the calendar year (Coughlin 1988, Partridge 1991). The initial year of a drought period was the first year when rainfall was less than 70% of the long-term mean (–30% anomaly). The drought period was considered to have ended when average (>95% of mean) or well above-average rainfall occurred. The proportion of 'El Niño' years (SOI for June to November ≤-5.5) during the extended drought periods in eastern Australia (western New South Wales, Queensland, and north-eastern South Australia; Episodes 1, 2, 4, 7, 8) was slightly less (23%) than the overall frequency (26%) of 'El Niño' years over the last hundred years (1890–2002). The proportion of El Niño years (23%) is similar even with the inclusion of regions with a weaker ENSO influence on rainfall (Gascoyne region and central Australia, Episodes 3 and 6). There was only one La Niña year (1964) in the extended drought periods for eastern Australia, and only two years (1938, 1964) when all regions were considered; this is in contrast to the overall frequency of La Niña years (22%, 1890–2002). Thus, not unexpectedly, the absence of La Niña conditions has been a major feature of the extended drought periods.

Table 1.1a Year type means expressed as a % deviation from overall mean (108 years) for annual (April to March) rainfall and simulated pasture variables (annual growth index, days per year when growth index ≥ 0.05 and native pasture growth). Year types are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Rainfall	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6
Menindee	-23.0	32.5	-5.3	1.8	10.5	-9.8
Wentworth	-14.1	32.3	-13.9	-8.1	15.6	-8.8
Olary	-17.2	25.0	-19.9	6.8	20.3	-7.7
Bourke	-26.1	27.5	-6.0	12.2	13.9	-10.6
Cobar	-12.5	29.9	-8.4	-3.5	16.2	-13.4
Quilpie	-26.5	41.2	-17.2	-0.3	19.9	-10.7
Gascoyne Junction	-16.1	27.8	-14.7	35.6	-4.1	-9.6
Alice Springs	-15.6	40.8	-8.7	3.3	5.5	-14.2
Charters Towers	-13.3	41.5	-33.6	-2.2	5.4	0.4
Average	**-18.3**	**33.2**	**-14.2**	**5.1**	**11.5**	**-9.4**

Annual growth index	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6
Menindee	-9.1	30.9	-6.4	0.6	4.2	-11.7
Wentworth	-0.4	26.4	-14.0	-1.6	8.3	-10.9
Olary	-9.2	36.7	-22.2	3.9	10.0	-10.4
Bourke	-18.7	25.5	-4.4	9.8	7.0	-9.5
Cobar	-9.8	23.6	-11.8	-2.3	14.7	-8.9
Quilpie	-21.7	29.6	-18.3	7.0	14.1	-5.4
Gascoyne Junction	-10.4	26.5	-14.4	31.0	-4.1	-10.4
Alice Springs	-15.1	34.6	-15.8	0.2	8.4	-7.4
Charters Towers	-12.4	32.4	-27.3	6.6	-0.5	1.6
Average	**-11.9**	**29.6**	**-15.0**	**6.1**	**6.9**	**-8.1**

Growth index days	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6
Menindee	4.8	12.9	-1.4	4.9	-2.8	-9.3
Wentworth	6.7	8.3	-8.2	3.8	1.7	-6.0
Olary	-1.5	27.7	-18.1	2.8	2.9	-7.3
Bourke	-13.1	15.9	-3.0	3.3	4.7	-4.1
Cobar	-4.1	13.4	-6.8	-0.3	9.3	-6.7
Quilpie	-20.1	20.5	-15.7	6.7	13.6	-2.2
Gascoyne Junction	-14.7	21.8	-7.3	18.2	-1.9	-6.0
Alice Springs	-16.8	22.5	-8.4	3.9	8.6	-5.3
Charters Towers	-10.4	16.3	-15.6	13.2	-6.5	3.9
Average	**-7.7**	**17.7**	**-9.4**	**6.3**	**3.3**	**-4.8**

Native pasture growth	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6
Menindee	-25.0	31.0	-5.0	-6.9	13.3	-6.4
Wentworth	-16.8	33.6	-19.8	-4.7	14.5	-5.4
Olary	-15.3	31.0	-31.8	6.4	25.5	-8.2
Bourke	-28.9	62.8	-14.8	14.3	-0.3	-16.9
Cobar	-15.7	73.9	-24.4	-21.7	26.2	-26.6
Quilpie	-21.4	75.2	-45.6	19.6	14.2	-20.6
Gascoyne Junction	-8.7	27.8	-27.9	75.4	-13.9	-15.0
Alice Springs	-12.9	24.5	-13.4	-1.3	11.4	-5.4
Charters Towers	-17.9	38.4	-47.7	15.5	9.9	3.5
Average	**-18.1**	**44.2**	**-25.6**	**10.7**	**11.2**	**-11.2**

Number of years	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6
All stations	16	17	17	11	17	30

Table 1.1b Percentage of years for each year type exceeding overall median (over 108 years) for annual (April to March) rainfall (mm/year) and simulated pasture variables (annual growth index, days per year when growth index ≥ 0.05 and native pasture growth, kg DM/ha/year) Year types are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Rainfall	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Median
Menindee	13	76	41	45	65	50	221
Wentworth	31	76	29	36	82	43	274
Olary	44	88	18	36	65	47	184
Bourke	19	76	41	73	65	40	343
Cobar	50	76	29	36	71	40	283
Quilpie	31	82	29	45	76	40	303
Gascoyne Junction	44	82	35	64	53	37	184
Alice Springs	63	65	35	64	53	37	224
Charters Towers	31	88	18	64	59	47	636
Average	**36**	**79**	**31**	**51**	**65**	**42**	**295**

Annual growth index	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Median
Menindee	38	88	41	45	59	37	19
Wentworth	50	76	35	45	65	37	22
Olary	44	94	24	36	65	40	15
Bourke	25	82	41	73	65	33	26
Cobar	44	82	29	36	71	37	21
Quilpie	25	88	29	64	65	40	24
Gascoyne Junction	38	71	41	82	59	33	12
Alice Springs	38	65	35	64	65	40	10
Charters Towers	19	100	12	64	53	53	26
Average	**36**	**83**	**32**	**57**	**63**	**39**	**19**

Growth index days	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Median
Menindee	56	76	53	55	41	33	80
Wentworth	63	71	29	55	47	33	88
Olary	50	88	41	36	53	37	65
Bourke	25	82	41	73	53	40	78
Cobar	44	82	41	64	59	30	73
Quilpie	19	82	35	64	71	40	68
Gascoyne Junction	31	71	41	73	59	37	39
Alice Springs	25	71	41	55	65	43	36
Charters Towers	13	88	18	73	41	63	62
Average	**36**	**79**	**38**	**61**	**54**	**40**	**65**

Native pasture growth	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Median
Menindee	19	88	47	45	65	40	763
Wentworth	31	76	24	45	76	47	914
Olary	44	76	18	64	65	43	593
Bourke	44	76	53	55	47	37	651
Cobar	44	88	35	36	59	40	498
Quilpie	38	82	24	73	53	40	273
Gascoyne Junction	44	65	35	73	59	40	207
Alice Springs	44	65	29	55	65	47	612
Charters Towers	19	94	12	64	59	53	1731
Average	**36**	**79**	**31**	**57**	**61**	**43**	**694**

Number of years	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
All stations	16	17	17	11	17	30	108

Table 1.1c Lowest value for each year type expressed as a percentage of the mean (over 108 years) for annual (April to March) rainfall (mm/year) and simulated pasture variables (annual growth index, days per year when growth index ≥ 0.05 and native pasture growth, kg DM/ha/year). Year types: are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Rainfall	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Mean	Worst year type
Menindee	44	73	45	52	29	32	241	5
Wentworth	42	69	37	58	37	40	285	3
Olary	36	65	19	54	53	38	205	3
Bourke	32	71	52	40	59	34	342	1
Cobar	44	77	47	38	60	32	309	6
Quilpie	35	60	21	36	51	26	332	3
Gascoyne Junction	35	46	19	38	36	11	203	6
Alice Springs	34	45	29	52	43	19	249	6
Charters Towers	48	79	37	60	41	51	643	3
Average	**39**	**65**	**34**	**48**	**45**	**31**	**312**	

Annual growth index	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Mean	Worst year type
Menindee	45	77	45	56	17	7	20	6
Wentworth	65	85	26	66	33	19	22	6
Olary	19	90	14	56	48	29	15	3
Bourke	37	76	43	45	62	37	25	6
Cobar	48	84	43	31	53	24	22	6
Quilpie	27	78	14	38	56	10	23	6
Gascoyne Junction	24	52	13	42	25	9	12	6
Alice Springs	33	52	22	50	30	14	11	6
Charters Towers	66	102	37	70	53	60	26	3
Average	**40**	**77**	**29**	**50**	**42**	**23**	**20**	

Growth index days	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Mean	Worst year type
Menindee	44	88	46	66	14	5	76	6
Wentworth	76	79	26	68	56	30	83	3
Olary	10	82	7	72	49	36	63	3
Bourke	45	81	51	48	78	55	76	1
Cobar	60	78	47	50	71	44	71	6
Quilpie	38	90	12	40	60	19	66	3
Gascoyne Junction	35	70	21	76	42	15	37	6
Alice Springs	38	64	26	58	43	24	37	6
Charters Towers	54	81	36	83	47	69	62	3
Average	**44**	**79**	**30**	**62**	**51**	**33**	**64**	

Native pasture growth	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Mean	Worst year type
Menindee	33	65	39	46	11	2	816	6
Wentworth	27	78	18	37	6	9	933	5
Olary	1	24	3	33	25	4	661	1
Bourke	3	61	9	16	29	4	816	1
Cobar	10	52	4	4	9	5	702	4
Quilpie	4	17	5	15	11	1	446	6
Gascoyne Junction	0	5	0	0	0	0	247	
Alice Springs	35	53	23	51	31	15	664	6
Charters Towers	40	101	13	19	29	18	1641	3
Average	**17**	**51**	**13**	**25**	**17**	**6**	**770**	

Number of years	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
All stations	16	17	17	11	17	30	108

Table 1.1d Number of years for each year type less than or equal to Decile 1 (over 108 years) for annual (April to March) rainfall and simulated pasture variables (annual growth index, days per year when growth index ≥ 0.05 and native pasture growth). Year types are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Rainfall	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	2	0	2	1	1	4	10
Wentworth	1	0	3	1	1	4	10
Olary	2	0	5	0	1	3	11
Bourke	5	0	0	1	0	5	11
Cobar	1	0	3	1	0	5	10
Quilpie	3	0	2	2	0	3	10
Gascoyne Junction	3	0	3	1	1	2	10
Alice Springs	4	0	1	0	1	4	10
Charters Towers	1	0	6	0	2	2	11
Average	**2**	**0**	**3**	**1**	**1**	**4**	**10**

Annual growth index	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	2	0	2	0	2	4	10
Wentworth	0	0	4	0	1	5	10
Olary	2	0	5	0	0	3	10
Bourke	5	0	1	1	0	4	11
Cobar	1	0	4	1	1	3	10
Quilpie	2	0	3	2	0	3	10
Gascoyne Junction	2	0	3	0	2	3	10
Alice Springs	3	0	2	0	2	6	13
Charters Towers	0	0	7	0	2	1	10
Average	**2**	**0**	**3**	**0**	**1**	**4**	**10**

Growth index days	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	1	0	2	0	1	6	10
Wentworth	0	0	4	1	1	5	11
Olary	2	0	4	0	1	3	10
Bourke	2	0	2	2	0	4	10
Cobar	1	0	4	1	1	3	10
Quilpie	3	0	3	1	0	3	10
Gascoyne Junction	2	0	4	0	2	2	10
Alice Springs	2	0	2	0	2	4	10
Charters Towers	1	0	5	0	3	1	10
Average	**2**	**0**	**3**	**1**	**1**	**3**	**10**

Native pasture growth	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	3	0	2	1	2	2	10
Wentworth	2	0	3	1	1	3	10
Olary	3	0	4	0	0	3	10
Bourke	4	0	2	0	0	4	10
Cobar	1	0	3	2	1	3	10
Quilpie	2	0	3	0	1	4	10
Gascoyne Junction	2	0	2	1	2	4	11
Alice Springs	2	0	2	0	2	4	10
Charters Towers	0	0	7	1	0	2	10
Average	**2**	**0**	**3**	**1**	**1**	**3**	**10**

Number of years	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
All stations	16	17	17	11	17	30	108

Table 1.1e Number of years for each year type less than or equal to Decile 3 (over 108 years) for annual (April to March) rainfall and simulated pasture variables (annual growth index, days per year when growth index ≥ 0.05 and native pasture growth). Year types are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Rainfall	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	7	1	8	1	4	11	32
Wentworth	6	2	9	2	3	10	32
Olary	6	2	11	1	4	8	32
Bourke	9	1	5	2	4	11	32
Cobar	5	0	8	3	2	14	32
Quilpie	8	2	6	2	3	11	32
Gascoyne Junction	5	1	8	3	2	13	32
Alice Springs	5	5	6	1	5	10	32
Charters Towers	7	0	12	2	3	8	32
Average	**6**	**2**	**8**	**2**	**3**	**11**	**32**

Annual growth index	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	4	0	9	3	4	12	32
Wentworth	3	1	10	4	4	10	32
Olary	4	0	10	1	4	13	32
Bourke	7	1	6	2	5	11	32
Cobar	6	0	5	4	3	14	32
Quilpie	8	1	7	2	4	11	33
Gascoyne Junction	6	1	10	2	2	11	32
Alice Springs	7	4	7	2	3	9	32
Charters Towers	7	0	10	3	5	7	32
Average	**6**	**1**	**8**	**3**	**4**	**11**	**32**

Growth index days	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	4	1	6	4	6	13	34
Wentworth	4	2	7	3	4	12	32
Olary	4	0	9	2	6	11	32
Bourke	9	1	6	2	3	11	32
Cobar	7	1	6	4	2	12	32
Quilpie	8	1	8	3	2	10	32
Gascoyne Junction	8	1	7	1	3	12	32
Alice Springs	8	3	7	2	3	10	33
Charters Towers	7	1	8	2	7	8	33
Average	**7**	**1**	**7**	**3**	**4**	**11**	**32**

Native pasture growth	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Menindee	6	1	7	4	4	10	32
Wentworth	7	2	10	3	2	9	33
Olary	5	2	10	1	4	10	32
Bourke	9	0	6	2	3	12	32
Cobar	6	0	9	4	1	12	32
Quilpie	7	1	7	3	4	10	32
Gascoyne Junction	5	3	8	3	3	10	32
Alice Springs	6	4	7	3	3	9	32
Charters Towers	4	0	13	2	4	9	32
Average	**6**	**1**	**9**	**3**	**3**	**10**	**32**

Number of years	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
	16	17	17	11	17	30	108

Table 1.1f The value for Decile 3 of each year type expressed as a percentage of the mean (over 108 years) for annual (April to March) rainfall (mm/year) and simulated pasture variables (annual growth index (%), days per year when growth index ≥ 0.05 and native pasture growth, kg DM/ha/year). Year types are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Rainfall	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All	Mean
Menindee	69.4	105.9	60.5	79.9	79.8	69.6	74.1	241
Wentworth	74.6	100.2	67.6	84.1	102.3	74.4	80.7	285
Olary	72.0	100.0	58.2	78.8	82.8	75.6	74.9	204
Bourke	50.4	102.0	75.3	98.5	94.6	63.7	75.6	342
Cobar	69.2	92.8	67.0	79.5	88.8	65.1	77.0	309
Quilpie	52.6	100.1	63.9	78.8	93.2	60.1	67.4	332
Gascoyne Junction	67.9	105.4	61.9	79.8	79.1	59.2	70.8	203
Alice Springs	56.8	73.7	62.0	80.6	71.7	64.1	71.9	249
Charters Towers	67.8	124.2	46.5	78.9	86.7	82.5	76.9	643
Average	**64.5**	**100.5**	**62.5**	**82.1**	**86.6**	**68.3**	**74.4**	**312**

Annual growth index	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All	Mean
Menindee	75.9	111.4	59.5	77.8	82.2	65.5	75.8	19.5
Wentworth	87.0	102.2	64.7	81.0	90.8	75.0	85.4	22.0
Olary	79.8	114.1	42.5	76.8	78.7	68.8	74.7	14.9
Bourke	52.3	119.9	75.9	102.9	84.0	75.1	79.4	25.2
Cobar	67.6	106.9	78.1	79.8	97.2	74.7	81.6	22.0
Quilpie	60.2	109.2	69.8	97.1	86.3	72.8	77.7	23.4
Gascoyne Junction	71.2	97.6	65.2	111.9	95.9	69.0	80.7	11.7
Alice Springs	53.3	76.8	71.2	84.6	79.0	71.2	73.8	11.1
Charters Towers	77.1	123.9	58.3	88.2	81.3	89.6	82.7	26.1
Average	**69.4**	**106.9**	**65.0**	**88.9**	**86.2**	**73.5**	**79.1**	**19.5**

Growth index days	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All	Mean
Menindee	93.0	105.5	86.0	91.9	88.7	76.4	91.9	76.1
Wentworth	104.9	103.6	79.2	100.4	98.7	83.1	97.3	82.7
Olary	79.5	119.5	65.5	80.9	74.0	74.9	78.9	63.4
Bourke	76.6	108.0	89.2	101.9	94.2	87.9	92.0	75.7
Cobar	84.5	106.3	83.2	83.2	98.2	81.3	88.9	71.0
Quilpie	61.0	112.2	68.4	95.6	105.1	89.2	91.4	66.2
Gascoyne Junction	67.4	104.5	68.0	104.0	94.3	69.9	83.6	37.3
Alice Springs	57.1	97.7	66.2	84.6	88.7	77.7	77.7	37.1
Charters Towers	83.4	110.9	69.5	103.0	74.7	92.2	88.7	62.3
Average	**78.6**	**107.6**	**75.0**	**93.9**	**90.7**	**81.4**	**87.8**	**63.5**

Native pasture growth	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All	Mean
Menindee	61.6	111.6	61.7	59.8	84.1	66.4	69.1	816
Wentworth	69.3	110.4	57.1	87.3	100.9	78.5	78.3	933
Olary	55.6	94.0	32.1	81.9	72.0	61.1	64.6	661
Bourke	19.4	84.5	38.8	69.0	54.6	40.5	49.4	816
Cobar	36.4	101.8	35.9	32.5	61.8	26.4	48.5	702
Quilpie	17.9	86.5	36.2	52.4	49.0	35.1	39.5	446
Gascoyne Junction	33.7	61.2	46.7	102.2	76.2	41.3	52.5	246
Alice Springs	55.5	79.9	73.8	71.5	81.5	73.7	75.6	664
Charters Towers	65.7	126.1	23.2	97.3	66.5	61.6	61.5	1641
Average	**46.1**	**95.1**	**45.1**	**72.7**	**71.8**	**53.8**	**59.9**	**770**

Number of years	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
All stations	16	17	17	11	17	30	108

Table 1.2 Annual rainfall (mm/year) in different year types and simulated pasture variables (annual growth index (%), days per year when growth index ≥0.05 and native pasture growth, kg DM/ha/year) averaged across nine locations in Australia's rangelands* (Menindee, Wentworth, Olary, Bourke, Cobar, Quilpie, Gascoyne Junction, Alice Springs and Charters Towers). Year types are:

Year type 1 – June to November SOI ≤ -4 and IPO *cool*
Year type 2 – June to November SOI ≥ +4 and IPO *cool*
Year type 3 – June to November SOI ≤ -4 and IPO *warm*
Year type 4 – June to November SOI ≥ +4 and IPO *warm*
Year type 5 – June to November SOI > -4 and < +4 and IPO *cool*
Year type 6 – June to November SOI > -4 and < +4 and IPO *warm*

Year type mean expressed as a % deviation from overall mean (108 years)

Variable name	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6
Rainfall	-18.3	33.2	-14.2	5.1	11.5	-9.4
Annual growth index	-11.9	29.6	-15.0	6.1	6.9	-8.1
Growth index days	-7.7	17.7	-9.4	6.3	3.3	-4.8
Native pasture growth	-18.1	44.2	-25.6	10.7	11.2	-11.2

% Years in each year type > median (over 108 years)

Variable name	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Median
Rainfall	36.2	78.8	30.6	51.4	65.4	42.3	295.1
Annual growth index	35.7	82.9	31.9	56.6	63.0	38.9	19.4
Growth index days	36.2	79.0	37.8	60.9	54.3	39.6	65.4
Native pasture growth	36.3	78.9	30.8	56.7	60.9	43.0	693.7

Worst year for each year type as % of mean (over 108 years)

Variable name	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	Mean
Rainfall	38.9	65.0	34.0	47.6	45.4	31.4	311.9
Annual growth index	40.4	77.3	28.6	50.4	41.9	23.2	19.5
Growth index days	44.4	79.2	30.2	62.3	51.1	33.0	63.5
Native pasture growth	17.0	50.7	12.7	24.6	16.8	6.4	769.6

No. of years for each year type ≤ Decile 1 (over 108 years)

Variable name	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Rainfall	2.4	0.0	2.8	0.8	0.8	3.6	10.3
Annual growth index	1.9	0.0	3.4	0.4	1.1	3.6	10.4
Growth index days	1.6	0.0	3.3	0.6	1.2	3.4	10.1
Native pasture growth	2.1	0.0	3.1	0.7	1.0	3.2	10.1

No. of years for each year type ≤ Decile 3 (over 108 years)

Variable name	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All
Rainfall	6.4	1.6	8.1	1.9	3.3	10.7	32.0
Annual growth index	5.8	0.9	8.2	2.6	3.8	10.9	32.1
Growth index days	6.6	1.2	7.1	2.6	4.0	11.0	32.4
Native pasture growth	6.1	1.4	8.6	2.8	3.1	10.1	32.1

Decile 3 for each year type as % of mean (over 108 years)

Variable name	Year type 1	Year type 2	Year type 3	Year type 4	Year type 5	Year type 6	All	Mean
Rainfall	64.5	100.5	62.5	82.1	86.6	68.3	74.4	311.9
Annual growth index	69.4	106.9	65.0	88.9	86.2	73.5	79.1	19.5
Growth index days	78.6	107.6	75.0	93.9	90.7	81.4	87.8	63.5
Native pasture growth	46.1	95.1	45.1	72.7	71.8	53.8	59.9	769.6

[*] The maps in Plate 1.5 indicate general effects derived from 'fitted' surfaces of historical rainfall. Tables 1.1a – f and 1.2 provide preliminary simulations for specific rainfall stations associated with each degradation episode. Issues of the best method of interpolation, constructing continental averages, and the reconstruction of daily climate data before 1957 are currently (2003) being researched. A limitation in simulating pasture growth has been the lack of historical climate data (temperature, humidity and solar radiation before 1957, and pan evaporation before 1970). For example, simulated near-zero pasture growth in some years for the Gascoyne location was partly the result of using average daily Class A pan before 1970.

Table 1.3 Extended drought periods (brown) during the regional degradation episodes in Australia's rangelands as described in detail in Chapter 2. The extended drought period associated with each degradation episode was calculated using regional rainfall (Figure 1.1, Plate 1.2). For consistency, a standard 12–month period (1 April to 31 March) was used. Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean. The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. For Episode 5 which involved woody weed infestation, the impact was not revealed until the later drought period of the 1960s. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5).

Region / Episode		Ten year period of significance for each episode									
Western NSW	Year	**1894**	**1895**	**1896**	**1897**	**1898**	**1899**	**1900**	**1901**	**1902**	**1903**
Episode 1	% Anomaly	+34	+1	-10	-10	-38	-24	-48	-46	-45	+7
Western NSW	Year	**1924**	**1925**	**1926**	**1927**	**1928**	**1929**	**1930**	**1931**	**1932**	**1933**
Episode 2	% Anomaly	+7	-5	-29	-13	-64	-44	+12	+29	-34	+4
North East SA	Year	**1924**	**1925**	**1926**	**1927**	**1928**	**1929**	**1930**	**1931**	**1932**	**1933**
Episode 2	% Anomaly	-7	-43	-6	-28	-59	-36	-4	-8	-34	-12
Gascoyne, WA	Year	**1932**	**1933**	**1934**	**1935**	**1936**	**1937**	**1938**	**1939**	**1940**	**1941**
Episode 3	% Anomaly	+69	+35	+13	-71	-46	-31	-54	-33	-57	+48
Western NSW	Year	**1938**	**1939**	**1940**	**1941**	**1942**	**1943**	**1944**	**1945**	**1946**	**1947**
Episode 4	% Anomaly	+1	-7	-11	-48	-5	-42	-55	+3	-6	-1
Western NSW	Year	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**
Episode 5	% Anomaly	+26	+19	-19	-34	-37	-15	-33	+23	-32	+20
Central Aust	Year	**1957**	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**
Episode 6	% Anomaly	-10	-37	-31	-56	-28	-48	-63	-57	-36	+82
South-west Qld	Year	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**
Episode 7	% Anomaly	+36	-19	-45	-39	-17	-20	-2	-37	-4	-22
North-east Qld	Year	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Episode 8	% Anomaly	+4	-57	+43	-37	-4	-27	-39	+2	+23	+83

ENSO does not, however, provide the full explanation of the extended drought periods. The first years (1898, 1925, 1935, 1941, 1958, 1964, 1984) included only two El Niño years (1925, 1941) and unexpectedly one La Niña year (1964). The average or above-average years that ended each of the extended drought periods (1903, 1930, 1941, 1945, 1966, 1968, 1988) included one El Niño year (1941) and only one La Niña year (1988).

The above analysis of the extended drought periods indicated that the majority (>75%) of years were 'neutral SOI'. This year-type also made up the majority of drought-breaking years. The understanding and forecasting of regional rainfall in these 'neutral SOI' years represents a major research challenge with substantial potential value for providing managerial advice. It is plausible, however, that at least some of these drought years were due to the inherently chaotic nature of the climate system, and events of this kind may be essentially unpredictable at a regional scale.

The extended drought periods occurred when the IPO index was *warm* (late 1890s, mid/late 1920s, 1930s, early 1940s, 1980s) or 'neutral' (mid 1960s) (Figure 1.3). Mantua and Hare (2002) also indicated that the two periods 1925–1946 and 1977 to the mid 1990s were dominated by *warm* PDO regimes. Similarly White *et al.* (2003) in their analysis of summer drought in Australia indicated the importance of particular phases of the quasi-decadal and inter-decadal signals in association with extended regional drought periods through the 20th century.

Whilst forecasts based on ENSO are important for year-to-year climate risk assessment and contribute to the scientific understanding and prediction of extended (multi-year) regional drought periods such as indicated in Table 1.3. Nevertheless a more complete understanding of the cause of extended drought is yet to be achieved.

Summary of ENSO and IPO effects

Clearly there has been a statistical association between rangeland rainfall variability and the climate forcings (ENSO and IPO). The dynamics of the IPO are not yet fully understood, and so it is not clear if these associations are causally related, nor is it clear if the IPO is predictable or persistent on decadal timescales. What is clear, however, is that the impact of ENSO on Australia has waxed and waned from decade to decade and from generation to generation. This variability can manifest itself in many forms, e.g. in a reduced number of La Niñas and/or El Niños occurring in a given decade. We have seen that in some periods a sequence of La Niñas has been followed by a severe El Niño and longer drought periods and this has played a role in some of the degradation episodes documented in Chapter 2. However, the majority of years in the extended drought periods were neutral ENSO years during *warm* and neutral IPO. It seems probable that inter-decadal variability of this kind will continue into the future. It is hoped that current research into the IPO will increase understanding of its nature and its connection with both ENSO and rangelands climate, and will ultimately underpin improved seasonal to inter-annual climate risk assessments.

1.2.4 Synoptic circulation systems

'Weather' is the result of synoptic circulation systems of low and high pressure that traverse the Australian continent. Associated variability in rainfall, temperature and wind drive the important processes of plant growth and soil erosion. Hence we briefly review recent studies on synoptic features relevant to rangelands.

Northwest cloudbands

Northwest cloudbands (NWCBs) have recently been identified as a major source of winter/spring rainfall in rangeland regions of western, central and southern Australia (Tapp and Barrell 1984, Wright 1997, Telcik and Pattiaratchi 2001). NWCBs are transient synoptic systems originating in the north-eastern Indian Ocean and resulting in an influx of tropical moisture diagonally across Australia from north-western Australia to Victoria (Crimp *et al.* 1997, Wright 1997, Telcik and Pattiaratchi 2001). They are most active during the April–October period and they make a substantial contribution to total winter seasonal rainfall: 80% in Gascoyne (Telcik and Pattiaratchi 2001); 60% in central Australia; 40% in Victoria; and some influence in western Queensland (Wright 1997).

There has been high year-to-year variability in numbers of NWCBs, the amount of rain, and extent of influence. NWCBs originate to the east of deep low pressure systems that form in the tropical Indian Ocean. They are the result of wind anomalies forced by SSTs, which are related to the Indian Ocean dipole phenomena (Watterson 2001), and so convective activity is important in their development, particularly as a means of injecting moisture into the mid-troposphere and south-eastwards along the band (Crimp *et al.* 1997). Currently there is active scientific debate on sources of year-to-year variability and the effects of NWCBs on rainfall. A major issue is whether the year-to-year variability is related to ENSO or is the result of independent variability in the Indian Ocean (Allan *et al.* 2003, Cai *et al.* 2003). Further research is required to allow historical reconstruction of NWCBs for the last hundred years. However, the necessary upper tropospheric observations are not available before 1960 and hence reconstruction for analysis of the early major drought and degradation episodes will be difficult.

Behaviour of high pressure systems

Variability in the behaviour of pressure systems is important not only in terms of rainfall but also wind strength and direction. The southern region of the Australian continent is positioned in the high pressure belt which ranges from latitude 37˚ South in February to 29˚ South in August (B. Pittock pers. comm.). Pittock (1975, 1978) identified variation in the latitude of the high pressure belt (or the sub-tropical ridge) as an important indicator of rainfall variability. For southern and eastern Australia, Pittock (1978) found significant correlations between annual rainfall and annual mean latitude of the 'surface high pressure belt over eastern Australia'. However, the correlations were lower than those between rainfall and the SOI in eastern Australia. Russell (1991) subsequently included an index of the latitude of the high pressure belt in the development of his forecasting systems for some cropping regions of Australia. However, long time series are not readily available and objective calculation procedures are yet to be formalised (N. Nicholls pers. comm.). Thresher (2003) has developed a composite of time series that suggest long-term poleward movement of the sub-tropical ridge over the last hundred years, and a change (from July to October) in the time of year that the sub-tropical ridge reaches its winter minimum latitude.

Investigation of temporal variations in regional rainfall has confirmed the importance of year-to-year variation in atmospheric systems. For example Nicholls *et al.* (1999, p. 29) reviewed research on the links between declining rainfall in south-west Western Australia and changes in atmospheric circulation:

> Allan and Haylock (1993) noted that rainfall in the south-west was strongly correlated with mean sea level pressure (MSLP) over the continent and over the ocean to the west and south. They noted that Perth MSLP and south-west June–August rainfall was correlated at –0.80. They suggested that changes in frontal activity would be involved in this relationship, and that long-term rainfall variations may be reflecting long-term modulations of mid-latitude frontal activity. Support for this hypothesis was provided by Ansell *et al.* (2000) and Smith *et al.* (2000). The latter paper demonstrates that the number of mid-latitude depressions just to the south of south-west Western Australia has declined in recent decades (see also Plummer *et al.* 1999).

Nicholls *et al.* (1999) further showed that a long-term 'change in the relationship between the atmospheric circulation and rainfall in the south-west [Western Australia] occurred sometime during the 1950s' (p. 31), and that 'the SOI essentially affects rainfall [in south-west Western Australia] on inter annual time scales, through changing the atmospheric circulation (as measured by Perth MSLP)'. Their study highlights the uncertainty of establishing cause and effect relationships between rainfall and indices of SST and atmospheric circulation. Subsequent analyses (IOCI, 2002) indicated that winter rainfall 'decreased sharply and suddenly in the mid 1970s by about 10–20%'. Further, Indian Ocean Climate Initiative (IOCI 2002) stated:

> The rainfall decrease accompanied, and apparently was associated with, documented change in large-scale global atmospheric circulation at the time.
>
> The decrease in rainfall, and the associated circulation changes, bear some resemblance to changes most climate models project for an enhanced greenhouse effect.
>
> However, the changes are not sufficiently similar to indicate that the enhanced greenhouse effect is responsible, beyond reasonable doubt, for the rainfall decrease. This decrease may simply reflect natural climate variability. Most likely, both natural variability and the enhanced greenhouse effect have contributed to the rainfall decrease.

Wind and soil erosion

Ward and Russell (1980, p. 96) studied long-term changes in winds in south-east Queensland from 1887 to 1977 since 'the direction of the wind in coastal southeast Queensland in July mostly reflects circulation patterns associated with anticyclones moving east across southern Australia'. They found that 'the period of greatest windiness, judged by the small numbers of recorded calms, extended from the early 1920s to the late 1930s, when dust hazes derived from inland areas were frequently recorded in Brisbane' (Ward and Russell 1980, p. 93).

The long-term trend did not appear to be related to any change in the latitude of high pressure systems. Ward and Russell (1980) concluded (p. 96) that:

> The higher numbers of southerly and southeasterly winds in Brisbane before 1933–37 imply that anticyclones then were developed less over the western bight than they are now [1977], and remained longer in the eastern bight and in New South Wales. The increased southeasterly and easterly winds in the mid '30s suggest that in these years the anticyclones stayed longer over the Tasman Sea.

Their study supports the view that relatively rapid and persistent changes can occur in circulation features of the climate system over Australia and in this case in association with two major drought/degradation episodes involving increased frequency of dust storms (McTainsh and Leys 1993). Ward and Russell (1980) also noted that the changes reflected worldwide phenomena including shifts in North Pacific trade winds on 'dust bowl conditions in American south west'. As indicated in previous sections, the changes in inter-decadal indices (e.g. Mantua and Hare 2002) support their hypothesis. They claimed that their examination showed that long-term Australian rainfall fluctuations were consistent with the long-term changes in ambient weather systems. The work of Ward and Russell (1980) has been highlighted by McTainsh and Leys (1993) in their review of wind-driven soil erosion as an example of how natural inter-decadal climatic variability (rainfall and wind) and over-stocking interact to produce major episodes of soil erosion.

Other atmospheric circulation features have strong effects on extreme wind. For example, in an analysis of the cause of the extreme dust storm of 23 October 2002, R. Leighton, a meteorologist with considerable operational experience, linked the synoptic development to atmospheric pressure anomalies in the Southern Ocean on the eastern coast of Antarctica. He provided the following view of synoptic mechanisms behind extreme events:

> Many events are instigated by synoptic systems that are many thousands of kilometres distant. Many memorable weather events that occur across Australia have been the result of a vagrant ridge or anticyclone in the Pacific Ocean or the Antarctic. These systems influence the movement of lows and cold fronts which affect Australia in many ways. The easterly movement of the lows and fronts could be inhibited. The positioning of major lows around the Antarctic may be misplaced many degrees of latitude northwards with the result that anomalous westerly airflow results over much of southern Australia. The severity of the abnormal weather event also relies on the orientation of the anticyclones and ridges (N/S, E/W etc.). This directs the movement of the lows and associated fronts.
>
> Regarding dust storms in the 1930s and 1940s there could be the possibility that there was more ridging off the Antarctic into the Southern Ocean during these periods which would have the effect of low pressure systems being placed further north than was usual and the associated westerly airstreams would cover much of eastern Australia, or there could be controlling ridge links between the Antarctic high and anticyclones placed over the oceans.

1.2.5 Solar variability and lunar tidal influences on rangeland climate

The devastating impact of rainfall variability on rural production has led many researchers over the last hundred years to search for external forcings (solar variability, lunar tides, planetary motions) and thus aid prediction (e.g. Jones 1939, Noble and Vines 1993, Treloar 2002).

Variability in solar activity on 10 to 12 year and longer timescales (80 to 90 years), measured as sunspot numbers, has been investigated as a possible source of variability in Australian rainfall (e.g. Ward and Russell

1980), and in particular western New South Wales rainfall (Noble and Vines 1993). However, mechanisms linking climate processes to solar and lunar tidal variability are still to be confirmed (e.g. Robock 1996, White and Allan 2001, Treloar 2002).

Noble and Vines (1993), in their analysis of the role of solar and lunar tidal variability in changing western New South Wales rainfall, were bold enough to suggest that it could be used in planning burning management on decadal timescales. However, without a mechanistic understanding of the link with climate processes, operational use by scientific agencies is unlikely to occur.

Folland *et al.* (1998) addressed the hypothesis that bi-decadal climatic variability could be ascribed to lunar tidal (18 year) or solar influences. They observed that the hypothesised links did not explain the greater importance of bi-decadal variability in the Pacific than in the Atlantic. However, Folland *et al.* (1998, p. 13) did acknowledge that 'solar influences may be enhanced through forced stratospheric ozone fluctuations' and indicated that mechanisms 'still need to be assessed'. As discussed in the next section it is only with the inclusion of some of these mechanisms in Global Climate Models that attribution of causes of variability can be assessed, (e.g. Robock 1996, Gillet and Thompson 2003).

1.3 Global trends in temperature, CO_2 and land use change

1.3.1 Global warming and CO_2

Analysis of over 100 years of records has identified general trends of increasing temperature (IPCC 1996, 2001). In the Australasian region similar trends are found in night-time maritime temperatures in the western Pacific (Salinger *et al.* 1996), in the Indian Ocean (Drosdowsky and Chambers 1998), and in the Australian continental temperatures (Torok and Nicholls 1996, Wright *et al.* 1996). The highest temperatures, especially overnight temperatures in eastern Australia, have been experienced since the 1970s.

The year 2002 had the highest day-time average temperature aggregated across Australia, exacerbating the drought through high (potential) evaporation (Bureau of Meteorology 2002, p. 10):

> In all, the nine months from March to November saw an all-Australia maximum temperature anomaly of +1.65°C, the warmest on record for this three-season period, eclipsing the previous record set in 1980 by a staggering 0.63°C!

and:

> The 2002 maximum temperature anomaly of +1.22°C was 0.31°C warmer than the previous record set in 1980. The exceptional warmth recorded during the year was the result of inter-annual temperature variability overlayed on the longer-term warming trend which has affected Australia and global temperatures for about 50 years.

The separation of natural variability and anthropogenic effects in contributing to the severity of the 2002 drought is the subject of current debate (e.g. Nicholls 2003).

Low temperatures limit plant growth especially in winter rainfall regions (Fitzpatrick and Nix 1970). Nicholls (1997) analysed historical wheat yields and climate data, and suggested controversially that the increase in minimum temperature in Australia was a contributing factor in increasing wheat yield over the last 100 years. Given that low night-time temperatures may also limit growth of native pastures (if moisture, nutrients and solar radiation are not limiting) it could be expected that similar effects have been occurring in the rangelands. However, equivalent long-term agronomic records of pasture yield do not exist, and, as yet, historical climatic records are not suitable for simulations to test this hypothesis.

Studies with Global Climate Models have evaluated possible causes of the observed global trends including solar variability, volcanic emissions, sulphate aerosols and greenhouse gas (GHG) emissions. Some of the rise in global temperature up to the 1930s has been attributed to changes in solar variability whilst recent increases are likely to be caused by increasing radiative forcing due to increasing concentration of GHG emissions (Mann *et al.* 1998) and hence are likely to continue.

The concentration of CO_2 has a direct effect on plant growth and water use (Gifford 1997). Concentrations have increased from 291 ppmv (parts per million by volume) in about 1880 to 311 in 1950, to 355 in the early 1990s, and 378 ppmv in 2003. Both field and controlled environment experiments suggest that plant growth might increase by 10–40% due to a doubling of CO_2 concentration (Gifford 1997). Thus only a small effect (<10%) would be expected to have occurred over the last 100 years. The role of increasing CO_2 in directly driving vegetation dynamics in rangelands is regarded as small compared to management effects (Archer *et al.* 1995). However, interactions between management and CO_2 responses could occur, for example increased burning opportunities due to increased grass fuel loads (Howden *et al.* 1998, 1999). In many natural systems plant growth is limited by availability of nutrients (nitrogen, phosphorus). Hence the effect of increasing CO_2 on growth may not be as great in these situations unless nutrient availability is increased either by human intervention or through soil warming transiently releasing additional nutrients as carbon is decomposed (Howden *et al.* 1998).

A major effect of increased CO_2 is to reduce daily transpiration resulting in higher soil water levels and change in surface energy balance (Gifford 1997). The impact of increased plant water use efficiency on latent heat transfer at regional scales is an area of active research. Simulations using Global Climate Models suggest that changes in regional temperatures of the order of 1°C are possible due to the effect of doubling CO_2 on plant water use.

The lack of long-term records of native pasture production, taken under defined and constant management conditions, is becoming a major deficiency in our ability to detect the effects of current trends in temperature and CO_2 on rangeland production (McKeon *et al.* 1998). Various studies (e.g. Hall *et al.* 1998, Johnston *et al.* 2000) have shown that long-term livestock carrying capacity is directly related to average pasture growth. Pasture growth is expected to change in response to future increases in CO_2 concentration and possible changes in rainfall, temperature, and evaporative demand. Field methods to measure pasture growth have been developed and demonstrated (e.g. McKeon *et al.* 1990, Day *et al.* 1997) and have been used to underpin operational rangeland models such as AussieGRASS (Carter *et al.* 2000). However, as yet we do not have a comprehensive and long-term field program to measure rangeland productivity.

At the time of writing (2003), various studies (e.g. IOCI 2002, Gillett and Thompson 2003, Karoly 2003, Nicholls 2003, Baines *et al.* unpublished) are examining recent (i.e. last 30 years) changes in major climate variables (e.g. atmospheric circulation, regional rainfall) with particular attention to the Southern Hemisphere. These analyses of recent climate data combined with simulation experiments using Global Climate Models indicate substantial changes in atmospheric circulation in the Southern Hemisphere consistent with anthropogenic influences of greenhouse gasses, stratospheric ozone depletion and aerosol emissions. Since these human factors are likely to continue, the implicit assumption in rangeland management that the next 30 years will be some sample of the variability recorded in the past needs to be challenged. The urgency for climate science is to provide more accurate estimates of future climate variability (especially rainfall, temperature, wind and evaporative demand) so that future grazier and policy decisions for rangeland management are more soundly based.

1.3.2 Climate change and the El Niño – Southern Oscillation

Recent studies (Nicholls *et al.* 1996b, Power *et al.* 1998a) have shown that the relationship between SOI and Queensland rainfall during the period 1972 to 1992 has different characteristics compared with the previous period from 1910 to 1972 thus raising concern about the use of statistically based systems for future rainfall forecasting.

Simulations have been made with Global Climate Models throughout the world over the last five years, in order to develop a better understanding of future patterns of the ENSO under enhanced GHG concentrations. Although an extensive series of simulations have been completed, the future behaviour of the ENSO is still uncertain. From a broad physical understanding of the ENSO, enhanced greenhouse conditions may have two main effects (Walsh *et al.* 1999). The first would result from a change in the mean state of SST patterns, particularly in the central Pacific Ocean (Knutson and Manabe 1998, Folland *et al.* 1999, Walsh *et al.* 1999). The second effect may be a possible change in ENSO variability as a ramification of shifted SST patterns, resulting in spatial shifts of trade winds, and seasonal variation of trade wind strength (Walsh *et al.* 1999). The scientific community has proposed two main contrasting scenarios of these possible future physical effects on the ENSO. The first suggests that the likely change will be an increase in the occurrence of an El Niño-type mean state (Meehl and Washington 1996, IPCC 1996, Tziperman *et al.* 1998, Timmerman *et al.* 1999, Cai and Whetton 2000). The second suggests that underlying physics may promote larger and more frequent swings between La Niña and El Niño modes of circulation (Cane *et al.* 1997, Hoerling *et al.* 1997, Knutson *et al.* 1997, Liu 1998). However, other studies (Power *et al.* 1998b) suggest that there might be no change at all in the frequency or magnitude of ENSO-driven variability. The contrasting scenarios highlight the uncertainty of the future climate of the rangelands!

Some indications of possible local impacts of global warming on the relationship of ENSO and Queensland rainfall have been investigated using the CSIRO fully coupled Atmospheric Oceanic General Circulation Model run for the period 1881 to 2705. The rainfall scenario generated by this particular simulation experiment suggests that enhanced greenhouse conditions would substantially reduce rainfall and pasture growth, and increase likelihood of 'drought' in Queensland using current rainfall criteria (Walsh *et al.* 1999).

However, the uncertainty with regard to the future behaviour of ENSO indicates that future planning of resource use should be directed at closely monitoring climate variability and maintaining a flexible and responsive capability to reduce resource damage that cannot be easily reversed.

1.3.3 Land use change

Large global changes have occurred in vegetation due to human activity. Over the last 300 years the global area of forests and woodlands has decreased by 19%, grassland and pastures by 8%, and large increases in croplands have occurred (Richards cited by Ramankutty and Foley 1998). Such changes could have modified important biophysical attributes such as albedo (reflection of solar radiation) and roughness with possible effects on global and regional climate (Ramankutty and Foley 1998).

The major regional changes that have occurred and are still occurring in Australia's grazing lands include:

1. extensive tree clearing (e.g. Burrows *et al.* 1988, Henry *et al.* 2002);
2. vegetation thickening where fire has been suppressed or not used as a management tool (Anon. 1969, Burrows 1995, Burrows *et al.* 2002); and
3. extensive areas of bare ground in extended drought.

Overgrazing causing removal of surface cover can affect energy balance through albedo and transpiration.

For example, studies on the Arizona–Mexico border show that overgrazing can increase regional temperatures (Couzin 1999). Global Climate Models are being developed to quantify these effects (Couzin 1999). Whilst not included in our study, these effects of land use change reported here are worthy of study at some future stage to determine to what extent regional drought or wet seasons can be amplified by land use.

For example, in a Global Climate Model simulation of inter-decadal climatic variability in the semi-arid grazing lands of the Sahel (northern Africa), Zeng *et al.* (1999, 2001) found vegetation changes enhanced inter-decadal variation 'substantially' but reduced year-to-year variability. Zeng *et al.* (1999, p. 1539) stated:

> The interactive vegetation modifies the precipitation though a chain of positive feedback loops. For instance, decreased rainfall leads to less water availability and reduces vegetation, which in turn leads to higher surface albedo and reduced evapo-transpiration. This weakens the large-scale atmospheric circulation by reducing the energy and water flux into the atmosphere column, thus further decreasing the local rainfall.

In summary the atmosphere and ocean has exhibited long-term fluctuations over the last hundred years that have been associated with variability in rainfall and other climatic variables (wind, temperature). Current research aims to better quantify the magnitude of the variability associated with the various kinds of natural and human influences. The challenge for climate science is to foreshadow the many factors affecting regional climate so that rangeland managers may better anticipate the impacts of future climate variability and change.

1.4 Global economic and political forces

Since European settlement of Australia, grazing enterprises have been conducted to make a profit. It is probably only in recent times that lifestyle choice has sometimes been given as an alternative reason for continuing with grazing enterprises which are only marginally profitable (ABARE 1999). Changes in prices received for livestock products have a major impact on profitability of grazing enterprises and affect decisions regarding stocking rate and hence land degradation.

The production of meat and wool in Australia has greatly exceeded the domestic demand and hence most of the income from livestock products has been derived from export markets especially in the case of wool. In the early to mid 1800s there was a surplus of meat production with little export opportunity and hence wool was the preferred enterprise (Deutscher 1959). However, the technology for exporting meat has changed over time: increasing exports of beef products from the introduction of boiling down works in the 1840s; canning in the 1870s (Daly 1994); frozen meat exports in the 1880s; chilled meat exports in the mid 1930s; and renewed live cattle trade in the 1980s (Lloyd and Burrows 1988). Thus Australian wool and meat prices have been subject to fluctuations resulting from global demand and competition.

1.4.1 Wool prices

The major influences have been summarised from Heathcote (1965), Lloyd and Burrows (1988), and Daly (1994). A rapid expansion of sheep and cattle numbers occurred from the 1840s to the 1890s, the colonial economies were 'buoyant' and in part were supported by various gold rushes. The 1890s provided a major check to expansion with a global depression, unemployment, bank collapses and industrial strife. For example, wool prices (Australian greasy merino, Figure 1.4) declined by 30% from 1890 (11 pence per lb) to 1894 (8 pence per lb). Wool prices increased in the late 1890s (15 pence per lb) only to decline rapidly in 1901 (8 pence per lb). Sustained recovery did not occur until after 1904 (10 pence per lb) with further increases occurring during World War I (16 pence per lb). Price fluctuated substantially in the 1920s (13 – 19 pence per lb)

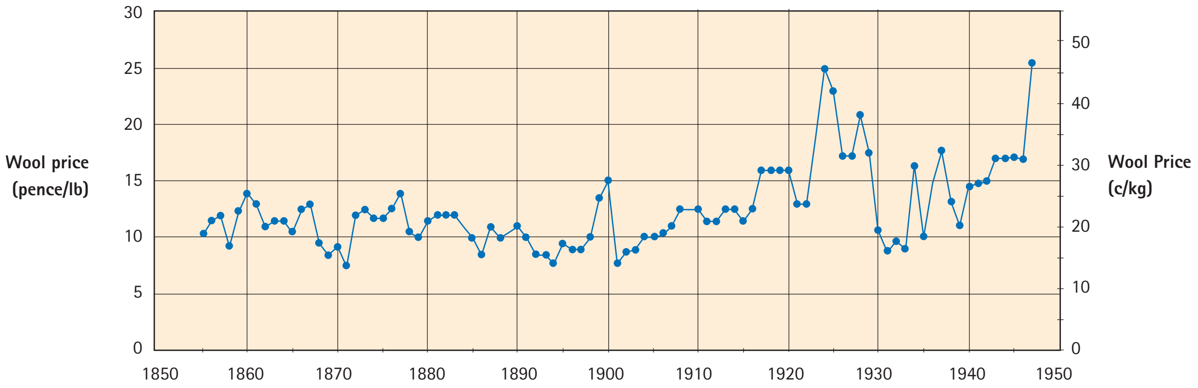


Figure 1.4 Australian greasy wool price (pence/lb and c/kg). Data from Vamplew (1987).

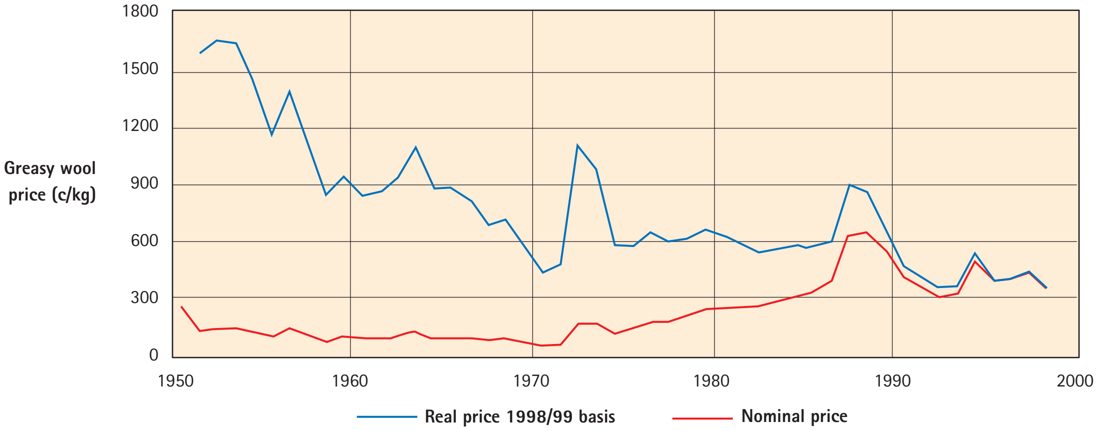


Figure 1.5 Mean Australian auction prices for greasy wool updated after AWC (1993), and adjusted by CPI (W.B. Hall unpublished, after Johnston *et al.* 2000).

with rises in 1924/25 (25 pence per lb) and rapid declines in 1925/26 (17 pence per lb). Prices further declined during the Great Depression (9 pence per lb), recovering in the late 1930s and with further price control as part of the war economy during World War II (17 pence per lb).

From 1945 wool prices increased with a spectacular three-fold rise from 1949 to 1951 at the start of the Korean War. Global and national inflation occurred after this point and continued until 1990 (Hall 1996) and hence prices (Figure 1.5) are best presented after adjusting for inflation (Hall 1996). Converted to 1998/99 dollars, prices show a general decline punctuated by short and unsustained recoveries in the 1950s and 1960s. The Australian Wool Commission was established in 1971 to support a floor price by buying and holding wool. For 20 years prices were relatively stable (Figure 1.5). In early 1991 the stocks reached a level equal to a full year's national production resulting in the termination of the scheme followed by price decline (AWC 1993).

In summary, up to 1950, the history of wool prices shows periods of: (1) decline 1860 to 1890s; (2) increase 1901 to 1925; (3) decline 1925 to 1939; (4) increase 1939 to 1950, and (5) decline since the 1950s. These periods were punctuated by: (1) rapid rises often associated with the outbreak of wars (WWI, WWII, Korean) or perhaps shortage of production, e.g. after the 1902 drought; and (2) rapid falls in some cases associated with the onset of global depressions in the 1890s and 1930s or for reasons as yet undocumented. For example, in relation to the falls in 1900 and 1925, we note that the Boer War (also called the South African

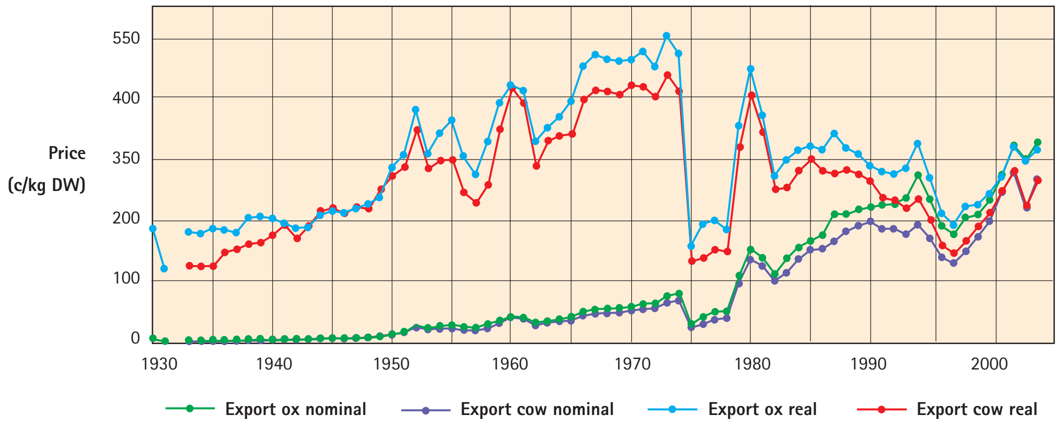


Figure 1.6 Annual nominal and real (adjusted to 2000/01) prices on a dressed weight (DW) basis for export ox (260–300kg DW) and export cows. Compiled by G.S. Stone and W.B. Hall from various sources including Daly (1983), and MLA statistical reviews, after Johnston *et al.* 2000.

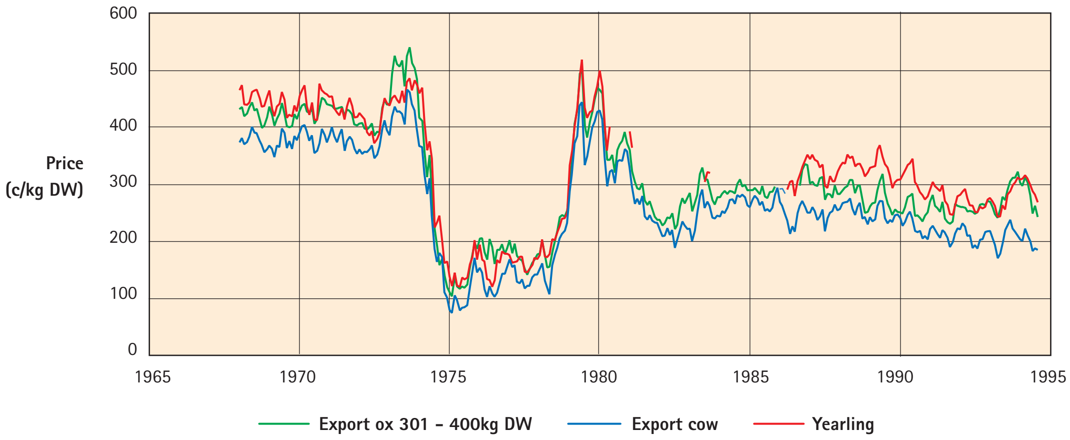


Figure 1.7 Monthly real (adjusted to 1996/97) prices on a dressed weight (DW) basis.

War) was drawing to a close in October 1900 and that in 1925 the European Locarno Agreement was reached to 'prevent future wars' in western Europe.

The period in the late 1930s had particularly high year-to-year price variation and was the subject of a detailed report to the Queensland government (Payne and McLean 1939). Some of the variation was attributed to the trade policies of Germany and Japan who were engaged in rearmament to support aggressive national policies and appeared to shift their import needs to South African wool producers.

1.4.2 Cattle prices

Detailed records for beef cattle prices are not readily available before 1930 (Daly 1983) although the technological changes in exporting meat, indicated above, stimulated expansion of the industry (Deutscher 1959). Daly (1994) comments on good prices in the 1910s and poor beef prices in the 1920s. The period after WWII was one of improving prices until 1973 when access to the USA export market was greatly reduced (Daly 1983). When converted to real prices the price time-series since the 1970s shows a general decline with rapid falls in 1974 and 1975 and increases in 1979 (Figures 1.6 and 1.7).

Cattle numbers in many areas of northern Australia increased in the mid 1970s partly in response to the rapid collapse in price (Tothill and Gillies 1992, Mann 1993). Several commentators (e.g. McKeon *et al.* 1990) regard it as fortunate that above-average rainfall (Figure 1.1, Plate 1.1) associated with enhanced 'La Niña' conditions (Figures 1.2, 1.3) occurred during this period.

The above description of climatic and price variability highlights the difficulty for graziers in managing stock numbers. Rapid declines in prices due to unheralded global forces effectively devalue stock and if these periods coincide with drought conditions (e.g. late 1890s in western New South Wales and Queensland, late 1920s in western New South Wales and South Australia, mid 1930s in Western Australia, mid 1960s in New South Wales and Queensland, early 1980s in Queensland), then graziers would be understandably reluctant to sell stock until absolutely necessary. This problem has been highlighted in central Australia by Young (1988, p. 119):

> With the retention of cattle on station – a strategy adopted by most non-Aboriginal pastoralists in times of low prices – destruction of this fragile environment is a very real threat. Between 1975 and 1979 almost every property in Central Australia would have been overstocked for this reason, and the only reason that disaster did not strike was that these years produced above-average rains.

1.5 Changes in grazing pressure

Grazing pressure is the ratio of forage demand from domestic, feral and native animals to forage supply. The failure to manage grazing pressure (over time and/or space) in a variable climate so as to reduce resource deterioration and allow for resource recovery has been seen as the major cause of rangeland degradation (Ratcliffe 1970, Tothill and Gillies 1992). The difficulty in controlling non-domestic grazing animals and the lack of knowledge of grazing pressure thresholds (e.g. Ash *et al.* 2002) have contributed to the risk of pasture degradation.

One of the major forces potentially affecting animal numbers has been the continued improvement in animal attributes (Gramshaw and Lloyd 1993), especially wool cut per sheep, survival of sheep and cattle during drought and flood, and reduction of the impact of pests and diseases (Lloyd and Burrows 1988).

Table 1.4 Periods of adoption of developing technologies in Queensland's grazing industries (P.W. Johnston pers. comm. G.S. Stone pers. comm.).

Technologies	Decade
Settlement	1850s
Sub artesian water	1860s
Artesian water	1890s
Fences	1900s
Steam engines	1900s
Cars/trucks	1910s
Bulldozers small	late 1940s
Electric bore pumps	1940s
Motorbikes	late 1950s
Chainsaws	late 1950s
4WD vehicles	mid 1950s
Bulldozers large	early 1960s
Beef roads	1960s
Roadtrains	early 1960s

Technologies	Decade
Bore piping	1960s
Poly Pipe	1970s
CB/UHF radio	late 1970s
Planes	late 1970s
Electric fences	mid 1970s
Helicopters	early 1980s
Ultralight aircraft	late 1980s
Rural power	late 1980s
Computers	late 1980s
Fax machines	late 1980s
Liveweight scales	1980s
Solar pumps	1980s
Satellite and mobile phones	early 1990s
Seasonal forecasting	mid 1990s

These changes have occurred as a result of:

1. technological advances in property and animal management (e.g. Table 1.4);
2. improvements in choice of breeds, with genetic selection and adaptation;
3. continued public investment in scientific research combined with community experience to develop 'agricultural knowledge systems';
4. disease control programs, e.g. tuberculosis and brucellosis;
5. public investment in infrastructure (e.g. transport) and natural disaster relief; and
6. access to information and education.

In rangelands the improvements in animal production and survival have allowed increases in stocking rate but have rarely been matched by increases in plant production. Initial increases in forage productivity of native grasslands in more humid environments were achieved by removal of tree/shrub competition for water, nutrients and light (Burrows *et al.* 1988). In higher rainfall regions further forage production increases have been achieved by sowing new pastures which were better adapted to higher fertility, and/or providing additional nitrogen through use of sown legumes (Lodge *et al.* 1984, Walker and Weston 1990). The intentional and sometimes unintentional introduction of palatable new species ('exotics') into the rangelands, especially for rehabilitation of degraded lands, 'has met with mixed success' (Noble *et al.* 1984). Some important exceptions are the tropical grasses, buffel grass (*Cenchrus ciliaris*) and Indian couch (*Bothriochloa pertusa*); pasture legumes such as stylos (*Stylosanthes* spp.), clovers (*Trifolium* spp.), medics (*Medicago* spp.); and the tropical shrub, prickly acacia (*Acacia nilotica*). The latter plant although valuable in terms of animal nutrition and shade is regarded as a weed given its ability to out-compete native grasses (Reynolds and Carter 1993, Carter 1994). Similarly, buffel grass, because of its widespread expansion (O'Rourke *et al.* 1992), has an equivocal status (Humphries *et al.* 1991) and has been listed as an environmental weed (ASEC 2001). Buffel grass has displaced native pastures particularly in arid inland Australia, forming monoculture swards along river systems, and increasing fire opportunities. Thus, despite its considerable value to the grazing industry in terms of pasture production, drought tolerance, speed of recovery and surface cover, buffel grass's capacity to threaten the integrity of natural ecosystems is a cause of major concern. These 'successes' are now controversial given the possible impact on biodiversity. Other releases of introduced plants have resulted in major weed problems (Lonsdale 1994).

1.5.1 Animal genotypes

The success of the rangeland grazing industries (especially in the tropics) has been based on the development of animal breeds able to utilise the plant material of low energy, protein and phosphorus concentrations. In particular the use of 'topfeeds' or 'browse' (i.e. plant material from palatable shrubs and trees) has been a key component of using native grazing lands as these relatively long-lived forages provide a forage store for times of drought (Ratcliffe 1970, Beale 1973, Lauder 2000a, 2000b).

Sheep and cattle of Australia's rangelands have remarkable attributes. Sheep are capable of wool growth even at levels of nutrition that result in substantial live weight loss. Both sheep and beef cattle exhibit compensatory gain (Hall 1996, Kidd and McLennan 1998) allowing rapid recovery during favourable conditions following periods of low nutrition. The reproductive potentials of sheep and cattle are high especially in non-lactating animals, and hence herds and flocks are capable of rapid increases under favourable nutrition.

Within sheep and cattle species there is substantial variation in genotype allowing selection and breeding for animals best adapted to a particular environment. For example comparisons of genotypes of Merino sheep in western Queensland showed that different genotypes were better at different levels of nutrition. The rearing environment is also likely to be important (Eady *et al.* 1990). Similarly, comparison of British (*Bos taurus*) and zebu (*Bos indicus)* beef cattle over a range of nutritional and environmental stresses has led to the use of different genotypes under different environmental conditions (Hall *et al.* 1998).

When compared to *Bos taurus* genotypes, cattle with a proportion of *B. indicus* genotype have: lower metabolic rates (Frisch and Vercoe 1969); lower weight losses (Robbins and Esdale 1982, Laing *et al.* 1984) at low nutrition; reduced conception rates at low cow weights (Holroyd *et al.* 1979) and hence greater breeder survival rates (Landsberg *et al.* 1998). *Bos indicus* cattle also have greater tick resistance, greater tolerance of high heat/humidity (Frisch 1973a, 1973b) and mechanisms for major reduction of metabolic rate under high stress (aestivism, King 1983). Not surprisingly, the change in genotype from *B. taurus* to *B. indicus* cattle in the 1960s and 1970s in eastern Queensland is seen as a contributor to increased cattle numbers and increased grazing pressure (Howden 1988, Tothill and Gillies 1992, Landsberg *et al.* 1998).

1.5.2 Grazing pressure and drought

Given the past importance of grazing industries to the national economy it is not surprising that the factors affecting survival of livestock during drought have been intensively studied (Webster 1973). Webster (1973, p. 150) noted that more than 100 million sheep were estimated to have died in 'the eight severe droughts that have affected the Australian pastoral industry since 1880'. Given 100 to 150 million sheep as the likely average annual national population over this time, these losses represent a substantial (>10% per drought) proportion of the nation's flock. Losses in affected regional areas have been higher than the national average and long-term property records show intermittent years with high death rates.

Studies on Merino sheep, reviewed by Webster (1973, p. 153, p. 158), have shown the various attributes that aid survival under conditions of low nutrition and drought: (1) minimum energy requirements to meet fasting energy losses decreased as fleece-free body weight declined; (2) 'emaciated sheep retained the capacity to produce heat at more than three times their rate of heat production in thermally equable conditions'; and (3) physiological capacity to conserve body water by 'concentrating their urine, minimising evaporative water losses, and tolerating bodily dehydration'; and (4) modifying grazing behaviour to reduce environmental stress.

Nevertheless, fasting and under-fed animals are susceptible to cold and wet conditions. These climatic stresses are thought to play an important role in mortality during drought (Webster 1973) or at the breaking of a drought when malnourished stock may be subjected to extended periods of wet and cold conditions. For example, D.R. Green (pers. comm.) observed in 1983 that 'when the drought broke in late March, rain killed weak sheep by both catching them in local flooding that they were too weak to move out of and by several days of wet and cold conditions when they could not forage – the initial heavy rain also removed most of the little remaining litter and leaf fall that the stock were surviving on. This impact was probably greater on roos at that time also and even affected goats.'

Before the widespread introduction of road transport in the early 1960s the movement of stock in drought was constrained by watering points, leading to considerable grazing pressure and erosion around property water supplies (frontage country and bores) and stock routes (Condon 2002). In an innovative and financially successful response to drought management, Sir Sidney Kidman developed 'chains' of properties in western Queensland, western New South Wales, South Australia and Northern Territory that facilitated movement of stock to market or other properties in response to the onset of severe drought conditions (Bowen 1987). However, for individual graziers without such a network, drought management had required difficult decisions of alternatively agisting, droving, selling, feeding by scrub-cutting or purchasing fodder, culling or, in the past, 'no action' (Hill 1973). The last option is no longer acceptable to the community and legislation

now requires timely intervention as part of drought management. For example, the New South Wales *Prevention of Cruelty to Animals Act (1979)* states that ' . . . the carer of an animal must provide at least maintenance feed to prevent the animal from distress and starvation, even in drought' (Clayton 2002).

Technological progress (Table 1.4) has brought major changes in the drought options used by graziers:

1. development of watering points to spread grazing pressure reducing concentration on individual points (Pickard 1990, Condon 2002), but resulting in grazing over a wider area and with the cost of the loss of biodiversity values (Landsberg *et al.* 1999);
2. better/cheaper road transport allowing more responsive movement of stock. However, the availability of transport may not necessarily lead to reduced grazing pressure in drought. Some graziers may have been tempted to retain stock longer into drought periods in the hope of a break (Bowen 1987) or return stock earlier not allowing enough time for pasture recovery;
3. increased national wheat production (Callaghan 1973) providing an economic feed source for sheep during drought whilst wool prices remained relatively high;
4. increasing use of urea/molasses has allowed increased consumption of low quality forages (Ernst *et al.* 1975);
5. financial support and 'tax instruments' from governments during drought reducing the combined impact of financial and climatic woes (Heathcote 1973, Daly 1994, Stafford Smith 2003); and
6. improved warning of the likelihood of drought especially associated with the onset of El Niño events (McBride and Nicholls 1983, Clewett *et al.* 1991, Stone *et al.* 1996, Drosdowsky and Chambers 1998).

In general, the improvement in the animal attributes of production and survival, and the continued improvement of technical, managerial and political capabilities, have reduced the impact of drought on animal production and mortality (Daly 1994). However, a consequence has been the potential to maintain grazing pressure on the natural resource during and following periods of drought (Tothill and Gillies 1992).

1.5.3 Feral and native herbivores

The other major components of grazing pressure (which are difficult to measure) are feral herbivores (e.g. rabbits, goats, horses, donkeys and camels), insects (e.g. grasshoppers and plague locusts) and macropods (Grice and Korn 1992). Rabbits expanded rapidly in numbers and distribution during the 1880s and resulted in periodic 'plagues' (e.g. Pickard 1990) contributing to feed shortages sometimes called 'rabbit droughts' (Condon 2002). Populations built up in favourable seasons and then declined markedly during dry conditions (Heathcote 1973, Bowen 1987). During the onset of dry conditions their effect was greatly noticed as they consumed perennial plant tissues (Donovan 1995). In dry times, rabbits will also ringbark the trunks of trees and shrubs (to 30 cm diameter), as well as climbing into the branches of shrubs to ringbark them. The release of myxomatosis in 1950 resulted in a major reduction of their numbers and hence greatly reduced the pressure on perennial plant species (useful and weeds alike). The release of rabbit calicivirus in the 1990s has had a similar effect with perceived increases in plant species abundance (Taylor 1998). Locusts have also had infrequent outbreaks resulting from favourable sequences of climatic conditions leading to population explosion and the consumption of pasture (Grice and Korn 1992).

With regard to kangaroos, Grice and Korn (1992, p. 115) state that:

> It is widely believed that kangaroo numbers have increased substantially in the inland since pastoral settlement. This increase is usually attributed to greater availability of reliable water supplies. Another idea is that stock

> improve pastures for kangaroos by grazing or trampling coarse grass, and so promoting the growth of the green shoots that are preferred by kangaroos.

Kangaroos have reproductive systems well adapted to fluctuating climatic conditions allowing rapid increase in animal numbers under favourable nutritional conditions. In areas of western Queensland their numbers are estimated to increase grazing pressure by approximately 40% (Pahl *et al.* 2000).

Conclusion

Thus the history of grazing pressure in Australia's rangelands is the result of interacting developments. Improvements in breed selection and genotypes have potentially increased grazing pressure, whilst technical and political developments such as watering points, fences and closer settlement have resulted in grazing pressure being distributed over almost the entire area of the non-desert rangelands. Whether or not closer settlement has led to an increase in grazing pressure is debatable (Donovan 1995, Condon 2002). Nevertheless, the uncontrolled population build-up of domestic, feral and native herbivores has inevitably led to high grazing pressure, especially in subsequent dry seasons (Shepherd and Caughley 1987, Pople and Page 2001).

1.5.4 Socioeconomic and institutional trends

The grazing industry has been subjected to other, more gradual changes over the longer term (Hall 1996). Labour costs have increased and, as prices received have also generally declined, the terms of trade for individual graziers have worsened, increasing the perceived need to stock more heavily to remain viable (Gramshaw 1995). The pastoral wool industry in particular has been adversely affected by the declining terms of trade with relatively low capacity to compensate with increased productivity. As the contribution to the national economy through exports and employment has declined so has political power. Governments have changed their policy from closer land settlement, especially after both World Wars (e.g. Pickard 1990), to support for property aggregation (e.g. Johnston *et al.* 1996a, 1996b). Community attitudes to environmental issues and the land rights of indigenous people have changed thus creating changes in security of land tenure and regulatory control on land management. Considerable variation still exists between the States in terms of legislative control of land management practices such as tree clearing and stocking rate (e.g. Donovan 1995). Thus the management of drought and grazing pressure has come under increasing public scrutiny over the last 100 years (e.g. *State of the Environment*, Anon. 1999).

1.6 Mechanisms of degradation in grazed rangelands

In the following section we describe mechanisms of degradation in rangelands that result in loss of productivity in terms of grazing value. The core desirable component of the rangelands used for grazing is the palatable perennial plant species (grasses, forbs and shrubs). These species provide: (1) animal nutrition especially in periods of extended drought; (2) soil surface protection from wind- and water-driven erosion; and (3) in the case of grasses, fuel for burning, e.g. to reduce density of woody plants. As the following review indicates the major loss of desirable perennial species generally occurs under the combination of heavy utilisation and drought.

Rangelands also include annual ephemeral species that are usually of high nutritional value when moisture is available but breakdown rapidly once conditions are dry (Hobbs *et al.* 1994, Richards *et al.* 2001). Hence ephemeral species do not usually contribute greatly to feed availability in drought, cover for soil protection, nor fuel for burning. However, some of the *Aristida* spp. and *Stipa* spp. and crowfoot (*Erodium crinitum*) are variable in their perenniality (i.e. can be annuals, biennials or perennials) and can contribute to drought feed, cover and fuel for burning. R.B. Hacker (pers. comm.) has observed that 'in fact *Stipa* spp. is a key species in

Table 1.5 Perennial grass basal cover after drought years and 'normal' or wet years for different pasture communities measured in grazing trials across Queensland (Data from Scattini 1973 and D.M. Orr pers. comm.). Values are shown for lightly grazed and heaviest grazed treatments in the trials. For all trials with the exception of Burenda, the Light grazing treatment was the most lightly grazed treatment in the experiment. For grazing trials on black speargrass and buffel grass, data for six years early in the trials have been shown. For grazing trials on Mitchell grass and mulga grasslands data from only the first major drought period have been shown. For all trials with the exception of Burenda, the first year's results were not considered, to remove the possible impact of previous grazing management history. The years of the measurement are indicated, usually between May and November after the growing season. In the case of severe droughts, e.g. 1980 in western Queensland, measurements were taken in the subsequent year (1981).

Location and Pasture Community	Drought years	% Grass Basal Cover		Heavy/light (%)	'Normal' or wet year	% Grass Basal Cover		Heavy/light (%)
		Light grazing	Heavy grazing			Light grazing	Heavy grazing	
Black speargrass	1964	5.81	4.43	76	1966	5.80	5.08	88
Brian Pastures	1965	4.93	2.83	57	1967	6.39	6.24	98
South-east Qld	1969	4.75	2.80	59	1968	7.89	10.80	137
Buffel grass	1970	6.12	6.17	101	1973	8.00	4.95	62
Eastwood	1971	7.23	4.10	57	1974	6.65	6.03	91
Western Qld	1972	7.90	2.10	27	1975	7.15	6.65	93
Mitchell grasslands	1978	3.60	2.10	58	1977	4.90	3.50	71
Burenda	1981	2.40	0.70	29	1979	4.50	2.60	58
Western Qld								
Toorak North-western Qld	1989	0.20	0.10	50	1987	2.60	1.90	73
Mulga grasslands Arabella South-western Qld	1981	1.12	0.50	45	1979	2.17	2.17	100
Average		4.41	2.58	56		5.61	4.99	87
Ratio of averages of heaviest to lightest grazed (%)				59				88

the winter rainfall rangelands as it provides the fine fuel that readily carries a fire. Major fire events usually follow two consecutive wet years that result in a large accumulation of *Stipa* spp.'.

1.6.1 Perennial grasslands

Perennial grasses, with either the C_3 (predominantly temperate species) or C_4 (most tropical grasses) pathways of photosynthesis, are the main understorey species in regions which have a substantial summer rainfall component (e.g. northern Australia, Tothill and Gillies 1992) or a reasonable continuity of moisture supply (e.g. south-eastern Australia, Lodge *et al.* 1984). Perennial grass plant 'density' is generally measured as grass basal cover (GBC). GBC fluctuates greatly with climatic conditions, with severe droughts causing substantial decline (Scattini 1973, Hodgkinson 1991, Orr *et al.* 1993).

Table 1.5 summarises measurements of GBC made in five grazing trials in Queensland ranging from coastal native pastures (black speargrass) to the low rainfall zone of western Queensland and including a range of soil fertilities (infertile mulga grassland to fertile sown buffel pastures). Extreme drought can cause high mortality of perennial grasses irrespective of grazing treatment (e.g. Toorak 1987/88 drought measured in 1989, Table 1.5). The combination of drought and heavy grazing results in lower GBC than would occur due to climate alone. Following drought years the percentage GBC under heavy grazing was 59% of the GBC under light grazing. For 'normal' (average rainfall) and wet (above-average rainfall) years, per cent GBC under heavy grazing was 88% of per cent GBC under light grazing. Thus, the combination of drought and heavy grazing substantially accelerates the decline in per cent GBC.

The above data indicate the rapid decline in GBC (i.e. over a few years) that can occur with combinations of drought and heavy grazing. Continued heavy grazing in subsequent years can continue the decline in GBC resulting in a near complete loss of 'desirable' perennial grass species. This occurred in the heaviest grazed treatments in most of the trials resulting in loss of productivity and/or vegetation change (Day *et al.* 1997) and a necessary reduction in stocking rate or time grazed.

At Toorak, D.M. Orr has followed cohorts of the long-lived perennial grass *Astrebla* spp. since 1984. In 1998, 18 and 24% of these plants had survived in the lightly stocked treatments (10 and 30% utilisation, respectively) whilst only 4% had survived at the heaviest stocking rate (80% utilisation).

Several mechanisms contribute to the rapid decline of perennial grasses under drought and grazing. Perennial grasses depend on substantial root systems to survive periodic drought and so allocate more photosynthate to roots with the onset of dry conditions. However, grazing or defoliation reduces the photosynthate available for partitioning to root growth and hence reduces root biomass resulting in a lower chance of survival under severe water stress (Howden 1988).

Some perennial grass species such as *Themeda triandra* have synchronous release of buds following drought. Heavy grazing at this time can remove all buds (Mott *et al.* 1992) resulting in death of the plants. For perennial grasses with low viable seed production (e.g. *T. triandra*) or transient seed stores (e.g. *Heteropogon contortus*) (Campbell 1995, McIvor and Howden 2000), recovery after drought is likely to be slow. For these reasons *T. triandra* is one of the first perennial grasses to disappear under heavy grazing (Howden 1988). For example the loss of *T. triandra* was observed after droughts in the 1880s in south-eastern Queensland (Shaw 1957).

Perennial grass 'death trap'

Hodgkinson (1991, 1995a) measured the survival of individual perennial plants of the dominant species (*Monachather paradoxa, Thyridolepis mitchelliana, Eragrostis eriopoda, Aristida jerichoensis*) in the mulga lands of western New South Wales. He found that the death of grass plants was accelerated by the combination of drought and previous heavy grazing. He coined the term 'death trap' in which heavy grazing sets up the possibility of substantial death once drought occurs (Hodgkinson 1995a): 'the trap is set by grazing and sprung by drought'. This understanding now forms part of the approach to tactical management of grazing pressure to maintain the stability of the perennial grass component (e.g. Hodgkinson 1995b, Hacker and Hodgkinson 1995, Hodgkinson *et al.* 1996, Lauder 2000a, 2000b, Campbell and Hacker 2000).

Thus knowledge of the susceptibility of desired perennial grasses to the combination of drought and heavy grazing has led to the recommendation of grazing systems based on either very conservative stocking or tactical reduction in stock numbers in response to developing or forecast drought. Similarly the importance of spelling during the growing season has been shown to allow restoration of desired pasture composition (Ash *et al.* 2002). More refined systems have been advocated such as 'tactical rest on rainfall' (Lauder 2000b) to improve pasture condition.

The loss of GBC of perennial grasses contributes to an amplification of degradation processes in several ways:

1. less competition with weeds and woody species, and reduced fuel for fire;
2. decreased infiltration, increased runoff and soil loss through water erosion;

3. increased soil loss through wind erosion; and
4. decreased nutrient cycling and lower soil microbial activity.

In the first case the result can be a shift to woody vegetation that out-competes perennial grasses for water and nutrients (Page 1997). Such shifts tend to be unidirectional (Burrows 1980). The main understorey species can become ephemeral or forb species (Carter *et al.* 1991) as grazing pressure continues on the remaining perennial grasses during dry periods. Carter *et al.* (1991) found no effect of woody weed density on forb biomass and hence in this case the impact of increasing woody weed density was likely to be a reduction in the drought reserve feed provided by perennial grasses.

In the second case the loss of available water (rainfall) and nutrients through increased runoff and associated soil loss amplifies the severity of drought and grazing resulting in bare ground and/or ephemeral species (Tongway and Hindley 1995). As the dead material of ephemeral species breaks down rapidly the impact of subsequent droughts on animal nutrition is likely to be amplified resulting in livestock mortalities or substantial destocking during these periods. The loss of the high infiltration micro-sites and the barriers to overland flow further reduce the productivity of the resource (Tongway and Hindley 1995, Pickup *et al.* 1998).

In the third case excessive surface soil loss often exposes less fertile and less permeable subsoils (e.g. producing scalded clay) and 'sand blasting' destroys remaining perennial vegetation (Beadle 1948) as discussed later (Section 1.7).

1.6.2 Perennial shrubs

Perennial shrubs are important components of rangelands, especially in regions of southern/central Western Australia, inland South Australia, western New South Wales and south-western Queensland. Chenopod shrublands commonly called 'saltbush' and 'bluebush' occur in semi-arid regions of southern Australia where winter rainfall is relatively reliable and effective (Graetz and Wilson 1984). Mulga woodlands also occur extensively in the rangelands where rainfall has both summer and winter components with mulga (*Acacia aneura*) providing a browse component especially in drought (Beale 1973, Wilson and Harrington 1984).

Where edible shrubs are found in high enough densities, they provide adequate and stable nutrition for animal production during dry periods. Green grasses and forbs, dry herbage (mainly grasses) are grazed in preference to annual and perennial chenopods (Graetz and Wilson 1984). This dietary preference hierarchy results in an 'inbuilt rotational grazing system' (Graetz and Wilson 1984) with concentration on shrubs only during dry periods and a rapid switchback to herbaceous species once effective rainfall has occurred. This release of grazing pressure allows shrubs to recover.

Graetz and Wilson (1984, p. 217) also presented evidence that the impact of chenopod shrubs on animal production is minimal and confined to drought years. They state that the 'key role' of shrubs is as a stable element providing 'long-lived resistant structures' in the landscape. Loss of edible shrubs through heavy defoliation 'exposes the land to invasion by less palatable poverty bushes and annual saltbushes, or to erosion of the soil surface' (p. 219).

Shrub species have lifetimes from short-lived (10 years) to long-lived (greater than 150 years, Graetz and Wilson 1984). Watson *et al.* (1997a, 1997b) studied the demography of two long-lived arid-zone shrubs (*Eremophila* spp.) under different grazing pressures. Stocking rate had no effect on the mortality rate of the unpalatable species but the mortality rate of the palatable species was double in the 'high' stocking rate treatment. For the palatable species, their analysis indicated that the effect of 'high' stocking was greater during drought, due to the additive effect of grazing and drought. However, over long periods of time (about

50 years) the total mortality over the non-drought years was approximately equal to mortality during the fewer drought years (Watson *et al.* 1997b). Leigh and Mulham (1971) also found that death of saltbush occurred due to excessive defoliation irrespective of moisture conditions. Hacker (1976) discussed factors affecting mortality of saltbush (*Atriplex vesicaria*) in the Western Australian goldfields during the drought of 1968–1973. Mortality was 44% for ungrazed plants and 65% for artificially defoliated plants outside the exclosure. In addition, there was a marked effect of size class on mortality in this study with greater mortality of small plants.

Watson *et al.* (1997a, 1997b) reviewed studies on demography of arid zone shrubs. They challenged the view that most of the mortality occurs in 'episodic events'. They found that for long-lived species drought episodes did not generally cause more than a 20% decline in population although shorter-lived species (e.g. bladder saltbush, *Atriplex vesicaria*) could decline by up to 100% through periods that included a drought.

Graetz and Wilson (1984, p. 213) also describe the 'catastrophic elimination of [bladder] saltbush over thousands of hectares' in eastern Australia although the cause of the phenomenon is unknown. 'Often the death of the saltbush coincides with the presence of plague numbers of army worms (family Noctuidae) and other insects but it has not been established that these are totally responsible'. R.W. Condon (pers. comm.) observed that grazed or defoliated plants were able to make 'vigorous growth' at the same time, suggesting that the lack of grazing also can predispose saltbush to these rapid losses.

Extreme drought is implicated in the substantial death of long-lived shrubs/trees. For example Watson *et al.* (1997a, 1997b) refer to the results of Cunningham and Walker (1973) in which a population of *Acacia aneura* declined by 75% during a 14–year period containing two droughts. Similarly Fensham and Holman (1999) measured 29% death (in terms of tree basal area) of adult *Eucalyptus* trees in north-eastern Queensland as a result of the 1991 to 1995 drought. They also reviewed historical accounts of episodic tree death in Queensland documenting several regional episodes (1901/02 in south-west and central, 1935 in west, central and south-west, and 1946 in south-west).

Thus in the case of long-lived shrubs and trees it appears that climatic extremes can produce substantial episodic death. However, when considered over long periods, mortality during droughts is of approximately equal significance to cumulative mortality outside drought. Excessive grazing also leads to increased mortality and this is exacerbated by drought.

Watson *et al.* (1997b) reviewed studies on recruitment of shrubs. They concluded that actual recruitment to a population should be regarded as a 'continuous' process as well as being found during specific recruitment episodes. Nevertheless, management changes such as removal of stock and pests (e.g. rabbits) could produce episodic recruitment events. In addition, significant rainfall-driven episodic recruitments have been observed, e.g. *Acacia nilotica* in western Queensland in the 1970s (J. O. Carter pers. comm.), and woody weed and shrub recovery in western New South Wales in the 1950s and 1970s (Condon 2002). From simulations of historical soil moisture conditions, Noble (1997a, p. 45) estimated that conditions favouring shrub germination in north-western New South Wales occurred every 15 to 20 years on average. Resolution of alternative views on recruitment of shrubs must await more quantitative modelling as discussed in Chapter 3.

Graetz and Wilson (1984) highlighted the importance of maintaining seed banks to ensure the continuing recruitment of desired perennial shrubs. Thus both Graetz and Wilson (1984) and Watson *et al.* (1997b) concluded that the sustainable management of the shrublands depends on continuous management of grazing pressure to conserve the perennial shrub component, rather than concentration solely on management in drought years.

1.6.3 Drought and plant growth

Many observers have commented on the flush of growth and healthy condition of pastures that have been observed when good growing conditions have followed drought (e.g. Shaw 1957, Perry 1962, Bowen 1987). Apart from the beneficial effect of reducing stock and other herbivore numbers, the extended dry period is likely to lead to a build-up of nutrients through the death of plant tissues (e.g. roots) and microbial biomass (Mott *et al.* 1985). These organic tissues decompose rapidly releasing nutrients once warmth and moisture occur at the break of the drought (Parton *et al.* 1988). The build-up of nutrients during drought is also attributed to repeated wetting and drying cycles that stimulate microbial action but are insufficient for extended plant growth – the 'Birch' effect (Charley and Cowling 1968). Perennial species, which have existing root systems, are well placed to rapidly absorb the available nutrients. Thus it is not surprising that drought has been referred to as 'nature's fallow' (Donovan 1995). The higher concentration of nutrients in plant tissues following drought flows through to the quality of diet selected by animals and can contribute to compensatory growth (Hall *et al.* 1998). Consequently, if grazing going into drought has not damaged vegetation, the plant/animal system can compensate to some extent for the periods of low rainfall (e.g. Perry 1962) as long as landscape function has not been profoundly altered (Ludwig *et al.* 1997).

Not as many studies have been conducted on the management of recovery of perennial species at the break of drought. Deferred restocking or tactical rest after rainfall (e.g. Lauder 2002b) provides the opportunity for recovery in contrast to the effects of maintaining stock numbers at the break of drought (e.g. Episodes 7 and 8, Chapter 2).

The above review highlights the impact of drought and grazing on accelerating the loss of desirable perennial species. There is a clear role for (a) climate forecasting before drought, especially 'dry' growing seasons, and (b) rapid stock reductions during the early stages of drought, so as to reduce the damage to the perennial resource base. However, probabilistic climate forecasts of 'drought breaking rains' may do more damage than good by encouraging the retention of stock.

1.7 Soil erosion

Condon (2002) has reviewed the history of land condition in western New South Wales over the last 140 years and hence provides a long-term view of the processes of degradation and recovery with particular reference to soil erosion. Graham *et al.* (1989) classified the forms of degradation from the viewpoint of conducting repeatable surveys (Table 1.6). More recently analyses concentrating on landscape processes (Tongway and Hindley 1995) are being applied in northern Australia and western New South Wales.

Table 1.6 Percentage of surveyed sites in western New South Wales with different levels and forms of degradation (from Soil Conservation Service of New South Wales 1987–88, Graham *et al.* 1989).

Degradation form	Nil to Minor	Moderate	Severe to Extreme
Sheet and rill erosion	99.9	0.1	0.0
Gully erosion	94.5	4.0	1.5
Wind erosion	75.4	18.7	5.9
Scalding	81.4	17.4	1.2
Woody scrub infestation	62.4	27.3	10.3

1.7.1 Processes of soil erosion

Because of his extensive experience in western New South Wales and the Northern Territory, we have used Condon's analysis of soil erosion processes. The following range of processes identified in his review of land condition of western New South Wales (Condon 2002) provides an understanding of the contribution of erosion to the degradation episodes described in Chapter 2.

Scalding

Scalds are always associated with duplex/texture-contrast soils (i.e. a loam or sandy loam surface on clay subsoil with a high proportion of exchangeable sodium) (Condon 2002). Scalding of these soils in which clay subsoil is exposed produces a near-impermeable clay surface resulting in high runoff and soil loss.

Condon (2002) held that texture contrast soils were particularly susceptible to erosion because:

1. the sandy loam surface is easily pulverised by excessive trampling;
2. stock concentrate on these soils because of nutritional quality due to high sodium levels in soil and rapid response of vegetation to light falls of rain;
3. these soils occur as elevated components of the landscape; and
4. feed quality and soil conditions favour rabbits.

As a result of these factors, Condon (2002) held that texture-contrast soils had suffered greatly due to high stock numbers and rabbits in the late 1800s. He suspected that the devastation began in the first severe drought after an area was first stocked. He further stated (p. 334) 'that there would be very few areas of texture-contrast soils in western New South Wales which have not lost all or most of the surface horizon'.

Wind sheeting

Condon (2002) used the term 'wind sheeting' to describe the eroded surface on non-duplex soils 'in which the influence of sodium on soil characteristics is absent'. The wind-sheeted surface is 'swept smooth' but, in contrast to scalded surfaces, allows some moisture to infiltrate and has the same soil characteristics as the original surface.

Sand drift

Drift refers to loose sand which can accumulate into miniature dunes. The main 'manifestations of drift' are: (1) coarse sand left behind on an eroded surface as particles too heavy to be moved and that tend to be arranged as ripples; and (2) fine and medium sand forming small and large dunes. Condon (2002, p. 336) hypothesised that 'ripple drift' actually protected the underlying surface against the action of wind and water and provided an 'ideal seedbed', a 'wealth of seeds' and 'rapid regeneration' following reasonable rain. In the case of drift and dune formation, the medium and fine sand is bounced across the bare surface dislodging soil particles. The silt and clay become dust whilst the sand piles up against any obstruction and sand-blasts vegetation. The processes of wind erosion are described in greater detail in the next section (Section 1.7.2).

Sheet erosion by water

The flow of water across sloping sections of the landscape and the cutting action of this flow lead to the formation of rills which join up down slope to increase velocity and cutting power, leading to shallow gullies 'which then work their way upslope'. Condon (2002, p. 338) points out that the roots of trees and shrubs are ineffective at preventing these erosion processes unless there is substantial ground cover. Gullying of flats at the bottom of slopes results in the run-on or overland-flow, which was previously available to plant growth, being drained from the landscape (e.g. Purvis 1986) and increasing flood problems further downstream.

Impacts on plant productivity

The above processes of soil erosion impact on plant productivity in a variety of ways:

1. scalding results in much lower infiltration whilst sheet erosion transports water more rapidly out of the system (Condon 2002);
2. loss of soil from profiles in which nutrients are strongly concentrated in the surface (e.g. infertile mulga lands) results in a lower potential for plant growth (Miles 1993);
3. invasion of woody plants usually results in lower surface cover of grasses, reduced infiltration and greater losses of water and nutrients;
4. if the erosion process results in a change of surface soil characteristics (e.g. such as scalding) then the use of 'waterponding' (Cunningham 1970) or the presence of different plant species is required to allow regeneration to occur, i.e. those species with widespread seed dispersal and ability to grow on limited moisture availability.

Condon (2002) points out that many of the processes associated with erosion are natural in the sense that they were likely to have occurred (albeit less frequently) in or following periods of low cover resulting from protracted droughts before the introduction of domestic stock.

1.7.2 Soil erosion by wind

Wind erosion has been a major component of the degradation episodes of the 1890s, 1920s, 1930s, 1940s, 1960s and 1980s. The history of soil erosion by wind in Australia has been reviewed by McTainsh and Leys (1993) and we draw on their analysis. Dust storms (e.g. Plate 1.8) provide the most spectacular, readily observed evidence of episodes of land degradation in terms of the transport of soil particles, the 'sand-blasting' of vegetation, and the burying of fences and buildings (Anon. 1901). However, McTainsh and Leys (1993) regarded wind erosion as the least well understood of erosion processes because wind erosion does not 'remove measurable layers of topsoil in a single event' and hence the damage to productivity is difficult to quantify. The main effect, as indicated above in Condon's review (Condon 2002), is a 'winnowing' of soil with easily transported material (organic matter, clay, silt and fine sand) being removed. The loss of these materials and associated nutrients can reduce potential plant production (McTainsh and Leys 1993).

Soil and landscape characteristics are the primary factors determining the susceptibility of a soil to erosion (Condon and Stannard 1956) – shallow texture-contrast soils scald when the surface horizon is blown (and washed) away; medium depth texture-contrast soils, especially with plenty of coarse sand, will produce ripple drift; deep texture-contrast soils (to 60–100 cm) will produce drift and small dune formation; deep sand produces drift and dune activation; firm loamy red earths produce wind-sheeting with little or no drift; and sandy loamy red earths produce wind-sheeting with moderate or plentiful drift.

Thus wind erosion is affected by soil particle size, cohesion between particles, and surface roughness. Vegetation cover, as trees/shrubs or surface litter, increases roughness and absorbs some of the force of the wind, and hence reduces drag on the soil surface. McTainsh and Leys (1993) cite the work of Marshall (1972) who found that the critical spacing of dry-land shrubs was '3.5 times the average of the maximum height of the vegetation'. Thus the processes that result in the death and removal of perennial shrubs (repeated heavy defoliation, drought, fire, ringbarking by rabbits) increase susceptibility to wind erosion.

Prostrate ground cover above 45% also substantially reduces wind erosion (Leys 1991). Thus the decomposition of plant material during drought through natural processes of decay and insect consumption (mainly termites), and/or consumption and trampling by stock and other herbivores also increase the risk of substantial wind erosion.

Wet surface soils are less prone to wind erosion and hence wind erosion is higher in semi-arid regions where surfaces are more likely to be very dry. However, soils can produce crusts in the drying process that can also be strengthened by lichen and other microflora (McTainsh and Leys 1993, Eldridge and Tozer 1997, White 1997). Experiments in south-west New South Wales conducted by Leys (1990, cited by McTainsh and Leys 1993) indicate that breaking of the crust increased risk of wind erosion by 30 times. The damage done by the feet of sheep in breaking the surface crusts has been regarded as a major cause of erosion (e.g. O. B. Williams cited by Bowen 1987, Tynan 2000).

McTainsh and Leys (1993) showed that a high proportion (66%) of the variation in average annual dust frequency can be explained by a combination of annual wind run and an index of soil moisture (precipitation minus evaporation). Wind erosion in arid lands can be regarded as a natural process, especially where soil conditions and extreme rainfall variability result in ephemeral rather than perennial vegetation cover.

As indicated earlier in this chapter the climatic elements of wind strength and aridity, which cause wind-driven soil erosion, are subject to high variability on annual, decadal and generational timescales. Thus, in the degradation episodes involving wind-driven soil erosion, both climate variability and management decisions that reduced cover contributed to soil erosion (Ward and Russell 1980, McTainsh and Leys 1993).

McTainsh and Leys (1993) document the history of dust events back to the 1800s from published accounts. Periods of high frequency (>2 events per 5 years) are 1895 to 1904, 1925 to 1929, 1935 to 1944, 1965 to 1969 and 1980 to 1989. However, there has been a general decline in the number of dust storm days since 1945. The likely causes are: (1) changes in wind strength (Ward and Russell 1980); (2) increases in woody plants following the high rainfall periods of 1950s and 1970s, accompanied by (a) a reduction in rabbit

Plate 1.8 Dust storm at Griffith, New South Wales on 12 November 2002. Winds accompanying the severe dust storm were estimated at 90 km per hour. Photo: Denis Couch, Griffith.

populations due to the spread of myxomatosis and (b) the lack of use of fire (Anon. 1969, Burrows *et al.* 2002); and, we would like to think, (3) improved grazing management in response to drought.

Figure 1.8 shows the time-series of annual Dust Visibility Reduction (DVR) calculated by G. McTainsh and K. Tews for Charleville (Queensland), Wagga Wagga (New South Wales), Mildura (Victoria), Alice Springs (Northern Territory) and Port Hedland (Western Australia). DVR is used to represent the intensity of a wind erosion event on a scale between zero and one, where a value closer to one is a more intense wind erosion event. The DVR is calculated from the visibility recorded during a wind erosion event. The equation used for the DVR is: DVR = 0.60014 – 0.1303 * ln (visibility), where ln is the natural logarithm and visibility is measured in kilometres. For example, a meteorological record of a wind erosion event with a visibility of 100 metres (0.1 km) gives a DVR value of 0.9. This is the visibility experienced during a severe dust storm event. The total annual DVR for a station is produced by summing the individual events.

The record for Charleville shows the distinct peaks in the degradation episodes and subsequent drought periods (e.g. 1944, 1964–1970 and 1979–1982, Figure 1.1d). The highest peak is in 1965 in the middle of Episode 7 in south-western Queensland. For Wagga Wagga the main peak was in 1944, consistent with severe dust storms recorded at the time (Condon 2002). Stations such as Mildura and Wagga Wagga are also likely to be influenced by areas of bare ground from cropping as well as from heavily grazed locations. The high values for Mildura would reflect the dust from mallee-farming areas in north-west Victoria and the Murray mallee in South Australia, whilst the values at Wagga Wagga reflect the dust from western New South Wales as well as northern Victoria (Condon pers. comm.). Thus the time series for Wagga Wagga supports the importance of the 1940s episode relative to other time periods in western New South Wales. The time-series for Alice Springs shows the increase in the frequency of dust storms from 1959 peaking in 1965 and then declining by 1970. The main period of high DVR was from 1960 to 1967 highlighting that the degradation episode of the 1960s (Episode 6, central Australia) was clearly different to the previous period of the 1950s and subsequent conditions of the 1970s and the 1980s. The time series for Port Hedland shows similar peaks to Alice Springs (e.g. 1965) indicating the general flow of dust transporting wind systems from central Australia to north-western Australia as described by McTainsh and Leys (1993).

Lack of historical wind data

Condon (2002) suggested that wind strength has declined since the 1930s/40s contributing to reduced dust storm frequency and intensity. The analysis of wind strength by Ward and Russell (1980) was cited as supporting evidence that the period from the 1920s to the 1940s was different to subsequent periods. The Bureau of Meteorology has recently (2002) collated the daily climate data for 50 stations back to 1910 and in some cases the 1890s. However, there are few long-term reliable wind run observations available to test the above hypothesis. Analysis of 9.00 am and 3.00 pm wind speed values is still in progress, but preliminary analysis for New South Wales stations shows that 3.00 pm wind speed (October–December) increased from 1910 to 1962 then declined to present values which are similar to the 1920/30s. However, the data have not yet been evaluated in terms of changes in method of measurement, units of measurement and time of measurement (due to daylight saving). We have included this preliminary analysis to highlight the importance of historical wind data as a contributing factor to dust storm frequency and intensity, and the need for further research on associated meteorological forcings linked to climate change (e.g. Baines *et al.* unpublished).

The difficulty of constructing historical time series is further exacerbated by the lack of upper-level meteorological data. R. Stone, climatologist and former operational weather forecaster, has provided the following expert opinion on the possible causes of extreme winds associated with dust storms:

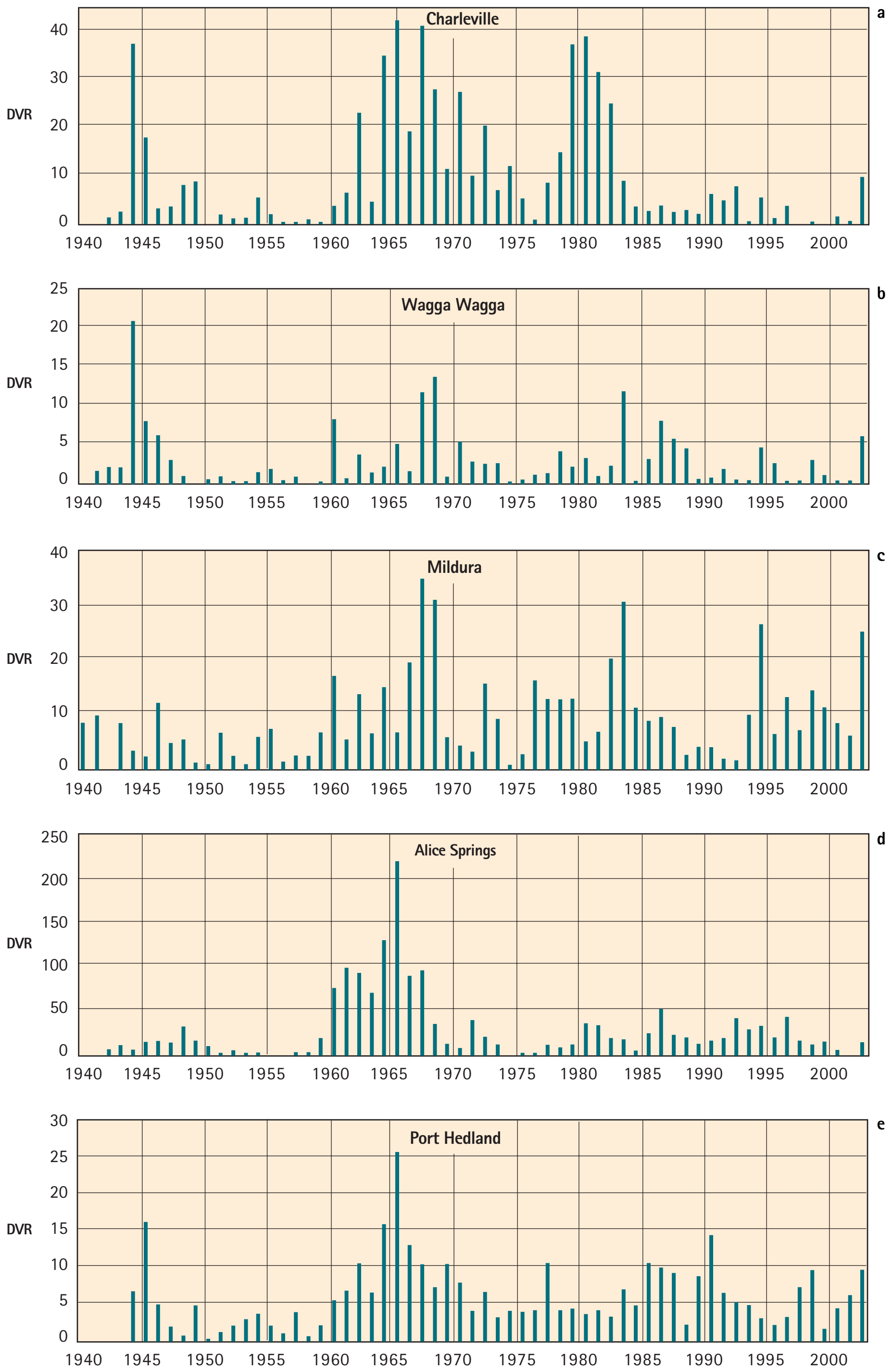


Figure 1.8 Time series of total annual Dust Visibility Reduction (DVR) at five stations (start year): (a) Charleville (1942); (b) Wagga Wagga (1941); (c) Mildura (1940); (d) Alice Springs (1942); and (e) Port Hedland (1944). Data time-series for Mildura are a composite of two stations; values for 1942 and 1943 for Mildura are not available. Data have been provided by G. McTainish and K. Tews. DVR is used to represent the intensity of a wind erosion event on a scale between zero and one, where a value closer to one is a more intense wind erosion event. DVR is calculated from the visibility recorded during a wind erosion event, e.g. a meteorological record of a wind erosion event with a visibility of 100 metres (0.1 km) gives a DVR of 0.9, and this is the visibility experienced during a severe dust storm event. The total annual DVR for a station is produced by summing the individual events. The equation used for DVR is: DVR = 0.60014 – 0.1303 * ln (visibility), where ln is the natural logarithm and visibility is measured in kilometres.

> While surface synoptic features certainly contribute to conditions favourable for dust and sand storm occurrence it needs to be emphasised that the strength of surface winds in inland areas of Australia is also associated with the strength of winds at higher levels of the troposphere. This is especially the case during the summer months when thermal mixing causes wind flow from well above the surface layer to reach ground level. This means that on days of high air temperature (and notably during 'drought' years) winds speed and direction can be more a function of upper-level dynamics than of surface synoptic conditions, although the two systems can also be interrelated. As a consequence of these conditions strong winds at, for example, 700 hPa may be induced to reach surface levels causing strong surface winds that would not otherwise be obvious from simple examination of surface synoptic features.

1.8 Woody weeds

The previous section dealt with soil erosion as the most obvious form of degradation. However, the increase in density of natural and exotic woody plants in grazing lands is also regarded as a degradation process where there is a loss of production from livestock (Booth and Barker 1981) and a loss of biodiversity. As a result such plants are called 'weeds'. The following review examines the processes of increase and expansion from this viewpoint and refers particularly to the dramatic infestation of woody weeds in western New South Wales described in Chapter 2. However, the more gradual process of 'vegetation thickening' of large areas of grazed woodlands is also important (Burrows *et al.* 2002).

Woody plants compete with perennial grasses for water, nutrients and light (Burrows *et al.* 1990, Noble 1997a, 1997b, Burrows 2002). The resulting stress probably renders the grasses more susceptible to the additional stress of grazing. Thus although grasses may coexist with relatively high densities of shrubs in ungrazed areas or exclosures, this is rarely the case under grazing (R.B. Hacker pers. comm.).

Generally grasses are capable of re-sprouting following fire whilst woody plant species vary in their tolerance with many species being disadvantaged or killed by fire (Noble 1997a). Noble (1997a) classified shrubs into three groups based on their response to fire:

1. extremely sensitive to fire (mulga, pine) with regeneration through seedling recruitment;
2. moderately fire sensitive (25–50% survival); and
3. tolerant of even wildfires with plants recovering by sprouting from stem bases and roots.

Noble (1997a) has reviewed the history of woody weed expansion since the 1800s with particular attention to western New South Wales and re-evaluated the findings of the 1901 Royal Commission (Anon. 1901) in terms of the effects on resource degradation. The Commission was mainly concerned with the economic plight of lessees and identified the growth of 'non-edible shrubs' as one of the causes of low profitability. Noble (1997a, p. 21) concluded that other factors documented by the Commission (low rainfall, rabbits, overstocking, wind erosion) all combined to increase woody weed densities by reducing fuel for burning which had previously eliminated young shrub plants:

> Potential fuel was either consumed by excessive grazing pressures or prevented from reaching previous biomass levels through accelerated erosion of topsoil. The elimination of vigorous perennial grasses also reduced the ability of such grasslands to out-compete shrub seedlings, especially during dry periods. The last two factors indirectly contributed to increasing shrub densities because pastoralists ran excessive numbers of livestock in a belated effort to grow more wool to offset diminishing commodity prices and increasingly submarginal property sizes. It is important to recognise though, as others have done, that all these factors are interdependent and it is their combined interactions, rather than their independent actions, which need to be considered in any analysis of vegetation change in these semi-arid lands.

Noble (1997a, p. 45) nevertheless strongly supported the role of fire in controlling woody plant density:

> Data from fire experiments on woody plants in western NSW and Central Australia are highly significant because they provide unequivocal evidence supporting the theory that frequent bushfires prior to European settlement were capable of maintaining open savannas by killing the majority of shrub seedlings germinating after fuel-generating rains.

Using the analysis from simulated historical soil moisture conditions, Noble (1997a p. 45) reported estimates that shrub germination events had occurred, on average, every 15 to 20 years. Fires at these times would have reduced the survival of shrub seedlings since there was enough soil moisture to grow sufficient fuel to carry fires every 5 to 6 years. Fires occurring at this frequency would also reduce flowering by many shrubs to almost zero thereby reducing seed production (Noble 1997a).

Noble (1997a, p. 46) emphasised the importance of fire in contributing to a 'vegetation mosaic' and the possible role of climate variability on inter-decadal timescales (Noble and Vines 1993) in driving wildfire frequency.

Rabbits and woody weeds

The role of the rabbit in woody weed expansion is difficult to separate from climatic variability. Rabbits 'were recognised as having a major deleterious impact on many of the edible shrubs' but 'the same unanimity of opinion was not apparent concerning their influence on other less palatable species' (Noble 1997a).

Examples of rabbits ringbarking woody weeds were reported by the 1901 Royal Commission and in biographical histories (Bowen 1987). Noble (1997a, p. 26) indicates that similar opinions regarding the impact of rabbits on woody plants resulted from the simultaneous spread of myxomatosis and woody shrubs in the wet 1950s:

> Because this occurred during an exceptionally good run of seasons, however it was difficult to determine how much of the shrub seedling 'pulse' was due to above-average rainfall and how much was due to a reduction in rabbit browsing of shrub seedlings.

Condon (1986b) was more 'assertive':

> Causes other than lack of fire have been ascribed, but cannot be sustained logically. The lack of rabbits due to myxomatosis in the 1950s was purely coincidental. The initial scrub invasion coincided with repeated rabbit plagues in the 1890s.

Thus these authors suggested that the pulses of woody weed infestation are driven primarily by climatic conditions favourable for germination and establishment, and in the absence of fire.

However, there are alternative views. For example, Green (1992) thought that, whilst the initial pulse of woody weed growth in the period from 1860–1900 occurred in conjunction with the rabbit invasion, the shrubs that increased were usually less palatable species (e.g. budda, turpentine, pine, and bimble box), and the infestation generally occurred on the harder country that rabbits had difficulty in colonising (e.g. Cobar Peneplain). In the sandy country which is good rabbit habitat, the increase in more palatable species, such as hopbush, was greatly accentuated after myxomatosis (e.g. for the west Darling area, Booth and Barker 1981). The two wet periods of 1956 and 1973/74 gave two pulses of germination and establishment in the absence of rabbits.

On reflection R.W. Condon (pers. comm.) added the following observations on the importance of the absence of rabbits:

> In 1952, pine seedlings were found in hundreds per square metre along a transect in tall thick grass which required inspection on hands and knees to see (certainly not degraded by erosion or sparse ground cover). Tall thick grass is a no-no for rabbits because they can't see their predators – so the rabbits would not have got near the scrub seedlings.
>
> The Great Central Scrub in the West Bogan country appeared amongst tall grass in the early 1880s, not becoming obvious until the grass died away in the early 1880s drought. By 1890 The Overflow station was poisoning and trapping rabbits in thousands. The rabbits were in plague proportions by 1890, too late to clean up the seedlings, and not enough to have much effect on the young scrub by this time.

Woody weeds and wind erosion

Whilst woody weed increase would be expected to reduce wind erosion (McTainsh and Leys 1993), Condon (1986b, 2002) and Leys (1991) draw attention to the cases where woody weeds actually accelerate wind- and water-driven soil erosion processes. Because of the competitive advantage of trees and shrubs over grasses (Burrows *et al.* 1990, Burrows 2002), little grass production occurs in low rainfall areas resulting in a mainly bare soil surface between woody plants. On sands and sandy loam soils, wind erosion can occur whilst on harder loam soils 'sheeting by water' can occur 'over extensive areas' (Condon 1986b). Direct measurement of soil loss in south-west Queensland confirms the accelerated soil erosion resulting from presence of woody weeds (Miles 1993).

Furthermore, R.W. Condon (pers. comm.) suggested that woody weeds with 'inverted cones or globes on sticks' increased wind velocity at ground level as the 'wind gets squeezed under the foliage'. He had observed ripple drift (e.g. Condon 2002, p.335) under punty bush at 5-10 m spacings, and wind sweeping the sand between turpentine bushes to pile it up in the litter at the base of the bushes which were 2-3 m high and at 5 m spacings on deep sands.

1.9 Recovery processes

The above review of degradation processes shows how heavy utilisation by domestic and other herbivores and lack of fire management can amplify the effects of climatic variability on resource productivity. In the case of drought, heavy grazing leads to increased death of desirable perennial grasses and shrubs, reduced soil cover, greater soil loss through wind and water impacts, and increased opportunity for woody weed infestation, further reducing plant production and protective soil cover. Thus degradation processes once initiated are not easily reversed.

There is general agreement that heavy utilisation resulting from climatic and economic forces drives degradation. However, there is considerable debate about the degree and causes of recovery (e.g. Pickard 1993). Because of the detailed documentation of degradation in western New South Wales (Table 1), the region provides a case study in the biophysical and socio-economic drivers of recovery. Condon (1986a) reviewed the processes of resource recovery based on his lifetime experience in western New South Wales. He identified 40 sites, described in detail in Condon (2002), which were regarded as 'catastrophically eroded' in the early 1950s 'or confirmed as such by present evidence of drifted-up fences and deep scalds, or written accounts' (Condon 1986a, p. 39). He further stated that 'all have undergone near complete reclamation'.

There were several factors that contributed to this 'dramatic recovery' (Condon 1986c):

1. improved rainfall regime in 1950s and 1970s and reduced wind strength (Ward and Russell 1980);
2. reduction in rabbit numbers;
3. breaking up of large stations reducing grazing pressure on woolsheds and water points;

4. 1950s wool boom providing money for fencing and more watering points;
5. road transport allowing stock to be moved rapidly in time of drought;
6. government drought relief schemes encouraging early destocking;
7. awareness of the effects of resource over-use especially under dry conditions; and
8. security of tenure providing incentive for property development.

Of the forms of degradation discussed above, scalding and woody weed encroachment present the greatest difficulties for regeneration.

Fundamental to recovery are the physical and biological regeneration processes. Condon (2002) describes in detail the recovery of scalds that were regarded as having little chance of reclamation. Wet periods (e.g. 1955–1956) result in low-lying parts of scalds being under water for several weeks providing the opportunity for recovery. Scald reclamation occurs with the leaching of sodium from the surface crust which reduces the propensity to seal and allows the surface to crack. These cracks increase water infiltration and catch seeds, thus promoting colonisation. The subsequent addition of organic carbon to the soil surface further improves infiltration characteristics and soil surface chemistry. Condon (1986a) pointed out that the recovery had occurred under normal stocking rates of domestic animals.

A comprehensive and objective view of resource condition in western New South Wales comes from the report of the 'first systematic survey of land degradation for the entire State (New South Wales) in July 1988' (Soil Conservation Service of New South Wales 1987/88, Graham *et al.* 1989). The Western Division was sampled at a 10 x 10 km grid (3085 points). The survey reports the percentage of sample points affected by particular types of degradation ranked from 'not appreciable' to 'extreme'. The survey also assessed the occurrence of edible perennial bush as a benchmark for future surveys. Given that the survey was the first of its type and has not yet been repeated it is not possible to estimate rate of change. Nevertheless the survey shows that substantial proportions of points (approximately 20% or more) had some form of moderate to severe degradation (Table 1.6; wind erosion, scalding, woody shrub infestation).

As Condon (1986a, 1986b, 1986c) observed 'woody scrub infestation' is the major form of degradation present. He estimated that carrying capacity had been reduced by 25–50% as a result of the loss of native pasture. The recovery from woody weed infestation requires either substantial periods of destocking for fuel build-up to carry a fire (Carter and Johnston 1986) and/or direct intervention (Noble 1997a).

The role of exclosure from grazing in recovery

On a relatively shorter time scale Silcock and Beale (1986) evaluated 17 exclosures commenced in 1964–1966 in south-west Queensland. They found that the exclusion of grazing animals had negligible effect on the botanical composition of strongly perennial species at most sites. They found that 'perennial grasses have not been able to recolonise scalded claypans even after twenty years exclosure, except where drifting sand is held by the fencing or fallen timber' (Silcock and Beale 1986, p. 152). This approach of surface modification with fallen or cut tree/shrub stems is now recommended as an approach for revegetation of difficult bare soil surfaces (Burrows 1970, Tongway and Ludwig 1996).

Exclusion of just domestic livestock does not necessarily improve the competitive advantage of palatable perennial species (Gardiner 1986a, 1986b, Silcock and Beale 1986, Page 1997, Page and Beeton 2000, Page *et al.* 2000). The studies of Gardiner (1986a, 1986b) in Western Australia and Page (1997) in south-west Queensland showed that complete exclosure of native and feral grazing was necessary for substantial increases in desired perennial plant species.

The recruitment of 'desirable' perennial plants requires: (a) presence of seed; (b) favourable climatic conditions; and (c) surface soil conditions for infiltration and nutrient capture (Hodgkinson and Tongway 2000). Exclusion of grazing alone does not necessarily result in beneficial change, e.g. Grice and Barchia (1995), Page and Beeton (2000), Page *et al.* (2000). If soil seed reserves are not available then transport of seed by wind and/or run-on from relic sites is needed. A sequence of favourable years is also required so that the cycle of seedling establishment to seed production can be completed several times.

Although Silcock and Beale (1986) found that woody plants were advantaged over grasses by exclosure, wild fires had a 'dramatic and valuable effect' in removing young mulga and Charleville turkey bush. Similarly Condon (1986b) refers to the wildfires of the 1920s in western New South Wales as temporarily setting back the infestation of woody weeds. Noble (1997a) describes wildfires in summer 1974/75 in western mallee country of New South Wales resulting in substantial benefits in herbage productivity. Wildfires in the Coolabah region of New South Wales in 1984 were regarded as the first for fifty years. Wildfires occurred in south-west Queensland in 1951 and were likely to have reduced woody weed expansion (G. Stone pers. comm., Hodgkinson *et al.* 1984). However, reliance on the beneficial effects of wildfires is a hazardous approach and more controlled methods for burning are recommended (Hodgkinson *et al.* 1984, Noble 1997a).

1.10 How have grazing enterprises coped with variability?

In Chapter 2 each episode is considered in terms of both degradation and (partial) recovery. The above analysis shows that the driving external forces in grazing enterprises, namely climate, pests and diseases, and economics, are subject to high variability and include extremes which are either potentially 'dangerous' to the survival of enterprises or provide opportunities for recovery of the enterprise and the pasture resource. Condon (2002) and others (Caughley 1987, Friedel *et al.* 1990) suggested that a general historical pattern occurred in which stock numbers built up in the boom period followed by an inevitable crash in drought. Yet despite this variability and initial difficulty, successful grazing enterprises have been developed and maintained over the last 140 years in arid and semi-arid environments (Friedel *et al.* 1990), contributing to the economic productivity of the nation (Newman and Condon 1969). Case studies of the successful property management especially through the extended drought periods are described in Chapters 2 and 4.

1.10.1 Stock numbers and degradation

Stock numbers would appear to represent the most readily available measure of the productivity of the grazing resource as they integrate a wide range of biophysical factors including variability in space and time, technological change and property development. However, the impact of degradation on carrying capacity is difficult to detect from time-series of animal numbers (Illius and O'Connor 1999) especially the relative attribution of causes to management factors as distinct from climatic variability. Illius and O'Connor (1999) draw attention to expressed views of some land managers, that unless there has been a loss of secondary production (i.e. animal products) then apparent symptoms of land and vegetation degradation may not necessarily be regarded as a loss of resource productivity.

In some regions where resource degradation is apparent, time series of animal numbers have shown: (1) reductions in peak numbers (Gascoyne, Wilcox and McKinnon 1972; Pastures Protection Districts in western New South Wales, Beadle 1948; Cobar–Byrock, Anon. 1969; central Australia, Condon *et al.* 1969a); and/or (2) increased responsiveness to drought (Jennings *et al.* 1979). However, a reduction in stock numbers does not necessarily show the impact of degradation on resource productivity and potential carrying capacity. Reductions in reported stock numbers at a regional scale can also occur because of:

1. changes in accuracy of reporting of stock numbers by graziers over time (Young and Miles 1982, Daly 1994, Mortiss 1995);
2. graziers adopting a more conservative view of safe carrying capacity (Johnston *et al.* 2000, Landsberg *et al.* 1998); and/or
3. a sensible managerial response to decadal climatic variation (e.g. Lilley 1973).

It is likely that all of the above have occurred to some extent and hence a more detailed study will be required to allow accurate interpretation of animal time series from a resource condition viewpoint. The irreversible degradation processes associated with soil loss (loss of water holding capacity and non-renewable soil nutrients), whilst rapid at a point or paddock scale, are likely to be slower at a larger regional scale and hence are not apparent in regional time series of stock numbers, especially in resilient systems. For example, simulations of the impact of soil loss on carrying capacity in southern Africa on a deep granitic sand suggest that, even at current high rates of soil loss due to heavy grazing, loss of productivity will be apparent only after several hundred years (Abel 1992). A complete loss of production in these heavily grazed African lands would take about 400–800 years to occur. Such simulations suggest that it would be difficult to detect the irreversible effects of soil erosion on temporal scales of decades and at regional spatial scales.

However, the degree of degradation under heavy grazing depends on the soil and landscape characteristics (Condon 2002). Certain soils and landscapes are more 'fragile' than the 'resilient' African systems above, and have degraded very quickly, especially those with strongly texture–contrast soils (Condon 2002). Alternatively, friable and self-mulching clays, such as those under Mitchell grass, can lose all ground cover under drought without substantial soil loss and have been able to recover, although not necessarily to perennials.

The conversion of open woodlands to complete dominance by woody weeds is also a slow process (Burrows 1995, Burrows *et al.* 2002). Such changes are commonly unidirectional (Burrows 1980) and irreversible from a current economic perspective. Nevertheless removal of unwanted plants is technically possible and has been demonstrated in field experiments. Proliferation of woody vegetation (woodland thickening and woody weed invasion) is yet to produce a complete loss of productivity from a carrying capacity viewpoint (Condon 1986b). Woody species may provide some feed through browse and litter (Beale 1973); and the growth of forbs can be independent of woody plant density (Carter *et al.* 1991).

Given the slowness of these degradation processes it is not surprising that the effects of degradation are not as apparent as the other influences which increase regional carrying capacity (e.g. property development, vegetation clearing). Thus, the fact that regional animal numbers are increasing or stable does not necessarily mean that resource degradation is not occurring.

1.11 Conclusion

1. The grazing system in Australia's semi-arid lands can be regarded as a flow of energy and nutrients wherein plants convert carbon dioxide, solar radiation and nutrients (nitrogen, phosphorus etc.) into tissues/organs that are consumed by animals to grow meat and fibre. These products are sold through to domestic and international markets. Graziers manage self-replacing herds and flocks, buying and selling as feed availability varies and personal preference dictates. In the semi-arid grazing lands, rainfall is the major limitation for the processes of plant growth, and survival of animals (and humans). Rainfall and/or wind also drive the processes of soil erosion and vegetation change (e.g. plant recruitment and mortality, fire). Thus climatic variability and change are key drivers of the biophysical component of the grazing system, e.g. the historical degradation episodes described in Chapter 2.

2. Rainfall variability from year to year especially in eastern Australia is partially driven by ENSO. However many of the years in the extended drought periods were sequences of non-El Niño years. The impact of ENSO events on Australia has varied from decade to decade and generation to generation. Recent work suggests that the IPO may modulate Australia's climate on inter-decadal timescales. For example, of the eight episodes studied here, seven occurred when the IPO was warm and one when the IPO was neutral. Other features of the climate system that affect degradation processes, such as the latitude of the high pressure belt, have also varied on similar timescales.

3. Graziers have developed breeds of animals and husbandry practices to increase production whilst managing for climatic variability. However, the retention of breeding flocks and herds in drought to preserve genetic gains can place considerable grazing pressure on the pasture resource resulting in lower animal production unless stock numbers are reduced. For example, a simulation case study of a grazing enterprise (South Australian rangeland, Stafford Smith and Foran 1992) indicated that responses of 20–40% destocking in drought were economically optimal, even without considering the resource benefits. However, in some cases, there has been a reluctance to reduce numbers because of economic conditions (e.g. low prices), financial assistance tied to Drought Declaration, small property size or ownership structure. In severe droughts, even 'economically optimal reductions' of 20–40% would be insufficient to match stock numbers to plant growth and hence the quantity (and quality) of conserved feed determines the consequences of drought for the grazier and resource alike. The remarkable survival attributes of domestic stock (sheep and cattle) combined with modern feed supplementation practices, allow grazing to be continued well into drought periods.

4. Rangeland degradation processes of soil erosion and woody weed infestation once started are amplified by continuing grazing pressure. Heavy utilisation of 'desirable' perennial species sets up the 'death trap' (Hodgkinson 1995a) and subsequent loss of perennial plants in drought. Matching of stock numbers (and total grazing pressure) to forage supply at both long-term and short-term timescales is necessary to reduce risks of damage to the vegetation and the land resource. However, the high climatic variability on annual and decadal timescales indicates the difficulty graziers face in achieving this objective.

5. Where degradation has occurred the subsequent removal of domestic stock has proven, in several cases, insufficient to allow recovery of 'desirable' perennial species. Several cycles of germination, recruitment and seed production are required and hence sequences of favourable moisture conditions lasting several years may be necessary for major recovery.

6. Favourable rainfall sequences in the rangelands of eastern Australia have been mostly associated with the enhanced La Niña pattern in the Pacific Ocean, i.e. when SSTs in the central Pacific were colder than normal, winter-spring SOI was strongly positive and the IPO 'index' was *cool*. This occurred in the early 1890s, 1916/17–1917/18, the mid 1950s, the early 1970s and perhaps the late 1990s. In fact the climate system has driven the apparent resilience of the land and pastures during these periods, especially the 1950s and 1970s as described in detail in Chapter 2. Further, the mismanagement of rangelands during these periods (overgrazing and pest build up in the early 1890s, property subdivision in the 1920s and 1950s, failure to use fire to control woody species in the 1950s, herd increases in 1950s and 1970s) has also been the precursor of subsequent degradation episodes.

Future climatic changes resulting from the combined effects of natural and human-induced forces are to be expected and are likely to include climatic episodes outside previous historical experience (IPCC 1996, IPCC 2001). The above review indicates that the role of climatic variability has not always been fully appreciated in the actions of individual graziers, or government policy, leading to episodes of mismanagement of the natural grazing resource as described in the next chapter. The challenge for graziers and governments alike is to use the understanding reviewed in Chapter 1 to prevent the next degradation episode.

Chapter 2

Degradation and recovery episodes in Australia's rangelands: An anthology

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2.1 Introduction

In this chapter we describe eight degradation episodes in terms of reported observations of degradation and of the likely contributing factors. We are conscious that we are writing at a considerable distance in time and space from the episodes and that the more recent episodes retain some community sensitivity. We don't seek to judge but rather to derive insight for future national benefit from what has occurred.

To this end, we have drawn on those commentators who have reviewed past episodes from ecological and resource management perspectives (e.g. Noble 1997a, Condon 2002). Where possible we have reviewed first-hand accounts by graziers (Purvis 1986, Ker Conway 1989, Landsberg *et al.* 1998), and newspaper reports of journalists explicitly commissioned to make the public aware of the impact of each episode (e.g. Millen 1899, Newman 1944a, 1944b, 1944c, 1944d, 1944e). We have also drawn on reports by government scientists and officials with first-hand experience. However, the task is not complete as our research continues to uncover insightful anecdotal evidence and 'grey literature' not readily accessible. In fact each episode is worth a report on its own. We conclude that we have but scratched the surface, and we hope this chapter will provide the impetus for further collation of archival material.

The episodes described here were traumatic experiences for graziers and governments alike, as previous reviewers have concluded (Pickard 1993, Drysdale 1995, Tynan 2000). By better documenting these sad events, we may learn to understand how they occurred and to what extent they could have been avoided. However, the understanding of climate influences on the extended periods of drought in Australia is just emerging (e.g. White *et al.* 2003) and hence we have indicated in each episode the extent of this current understanding and the need for future climate research.

As stated in Chapter 1, we have used the term 'degradation' to encompass both reversible and irreversible resource damage. Together, grazing management and climate variability had an impact on resource degradation and recovery. The extent to which each was responsible is the subject of debate. There has also been substantial debate in defining 'degradation' in terms of: (a) reversibility (i.e. recovery); and (b) the time period and economic inputs required for recovery (Tothill and Gillies 1992). We argue that the definitive discrimination in terms of 'reversible' and 'irreversible' is apparent only with the benefit of hindsight (e.g. Cunningham 1996). Thus, rigid attempts to define 'degradation' obscure the fact that degradation and the associated loss of productivity occur on timescales from years to centuries (as discussed in Chapter 1). A precautionary approach would lead to the view that any observation that degradation is occurring, or has occurred, indicates that the resource is not being sustainably managed.

General method of analysis of the effects of climate variability in the episodes

We have assessed each of the historic episodes in terms of both 'degradation' and 'recovery'. For each episode we describe data sources, a brief chronology, comparison of time series of climate, pasture and animal numbers, and where possible first-hand observations and analysis. At the end of this chapter, we summarise the 'average' pattern of degradation and recovery across episodes. We have included extensive quotations to preserve the originality of eyewitness accounts and reviewers' insights. We believe that the quoted authors have chosen their words carefully and were well aware of the political implications and sensitivity of their observations and reviews in the context of the time at which they were written. Hence we have not sought to dilute or paraphrase their evaluations and we refer to this chapter as an 'anthology'. At the end of each episode we pose the question: 'What do we learn for preventing land and pasture degradation under future climate variability?'

We analyse each degradation episode in terms of the history of rainfall, example simulations of pasture growth, reported stock numbers and climatic forcings such as ENSO and IPO/PDO. As indicated in Chapter 1, the following analyses of phases of the inter-decadal signals have the considerable benefit of hindsight. Forecasting skill for decadal and inter-decadal timescales does not exist (Mantua and Hare 2002) at the time of writing (2003). Nevertheless, the following analyses of the drought/degradation episodes highlight the need for this capability. Distribution of rainfall, especially during drought periods, can greatly affect the extent to which water is available for pasture growth. Hence, a better estimate of the impact of drought on pasture growth was provided by example simulations conducted with the soil water balance – pasture growth model, GRASP (Littleboy and McKeon 1997, Rickert et al. 2000).

As part of the AussieGRASS project (Hall *et al* 2001), GRASP was parameterised for the various communities in Australia's rangelands using data from historical grazing trials. In the following description of each episode, we identify these parameter sets using general vegetation terms: 'perennial grass' based on mulga grasslands at Arabella, south-west Queensland (Orr *et al*. 1993); 'herbage' involving a range of understorey species e.g. annual and perennial forbs and grasses, ephemerals and sub-shrubs, with parameters derived from pasture measurements at Kinchega, western New South Wales (Robertson 1987); central Australian 'herbage' derived from measurements near Alice Springs, Northern Territory (Hobbs *et al* 1994); Gascoyne 'herbage' in the chenopod/acacia shrublands derived from measurements at the Boolathana grazing trial (near Carnarvon), Western Australia (Holm 1994, Watson et al. 1997a); and 'tropical native pasture' derived from measurements at the Kangaroo Hills grazing trial, north-eastern Queensland (Gillard 1979). Preliminary simulations of pasture growth were made for representative locations using historical rainfall data (from 1890), and historical climate data (temperature, humidity and solar radiation from 1957, and pan evaporation from 1970).

A dynamic grass basal cover model was used in the simulation of 'perennial grass' and 'tropical native pastures' to account for the effects of drought on year-to-year variation in grass basal cover. The model represented the general decline in vegetation condition and productive potential during drought. In contrast, the other vegetation types ('herbage') were assumed to have, under conservative stocking rates, a constant growth potential and hence showed less effect of extended drought in the simulation studies. The simulations for 'perennial grass' at Charleville, south-west Queensland included the effects of increased run-off that can occur due to low cover for some time after the drought period. Simulations were conducted assuming conservative stocking rates, and hence represent pasture growth for a resource in reasonable and resilient condition. Nevertheless, extended periods of very low pasture growth were simulated, supporting the apparent amplification of severe drought under low rainfall conditions. For episodes in western NSW simulations of pasture growth used both 'perennial grass' and 'herbage' parameters to estimate the impact of drought and grazing on the ground storey layers for different types of vegetation. In the summary analysis (Chapter 2.10), the more appropriate vegetation parameter set for each episode has been used.

2.2 Episode 1: Western Division of New South Wales in the 1890s

In the 1890s western New South Wales experienced a dramatic fluctuation in rainfall from well above-average years of the early 1890s to severe and extended droughts of the late 1890s culminating in the extreme and widespread drought of 1902 (Gibbs and Maher 1967). The climatic fluctuation amplified the economic woes of the 1890s depression (low wool prices and industrial strife, Heathcote 1965). E.D. Millen toured western New South Wales and wrote seven extensive articles between November 1899 and January 1900 for the *Sydney Morning Herald*, describing the devastating impact on the natural resource, as well as on the livestock and the social resources (Noble 1997a). These articles initiated a Royal Commission 'to examine the condition of Crown tenants in the Western Division of New South Wales' (Noble 1997a). Submissions to the Commission subsequently revealed that substantial resource degradation was occurring and this was confirmed by subsequent reviews (Bean 1910, Beadle 1948, Green 1989, Noble 1997a, Condon 2002).

Table 2.1 Extended drought period (brown) during regional degradation Episode 1 in western New South Wales. The extended drought period was calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12-month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5). Years in the table are indicated only by the starting year, i.e. 1886 is the period 1 April 1886 to 31 March 1887, referred to in the text as 1886/87.

Episode		Rainfall Anomaly									
Episode 1 Western NSW	Year	**1886**	**1887**	**1888**	**1889**	**1890**	**1891**	**1892**	**1893**	**1894**	**1895**
	% Anomaly	+114	+23	-52	+105	+70	-5	0	+39	+34	+1
	Year	**1896**	**1897**	**1898**	**1899**	**1900**	**1901**	**1902**	**1903**	**1904**	**1905**
	% Anomaly	-10	-10	-38	-24	-48	-46	-45	+7	-20	+13

Climate and grazing history

Table 2.1 and Plate 2.1 show the 20–year history of rainfall anomalies for western New South Wales from 1886/87 to 1905/06 including the extended drought period from 1898/99 to 1902/03. The period from 1886/87 to 1895/96, preceding the extended drought had mostly average to well above-average years. Four of these years were associated with La Niñas (1886/87, 1889/90, 1892/93, 1893/94). There were two El Niño years during this period with below-average rainfall (1888/89, 1896/97). In the extended drought period only 1902/03 was an El Niño year (based on the June–November SOI). However, the SOI was also consistently negative in October for the years 1900/01 and 1901/02. Other analyses have indicated that 1899/1900 was also a weak El Niño and hence the period '1899–1902' has been previously described as a 'tripling up' of ENSO (Allan 1988, p. 334). However, the possible contribution of protracted ENSO behaviour to this extended drought period remains the subject of climatological research.

The IPO index was *cool* for the period 1889 to 1895, conditions when strong correlations between eastern Australian rainfall and SOI have occurred (Power *et al.* 1999, Table 1.1 in Chapter 1). The above-average rainfall during this period, especially in association with La Niña years, e.g. 1889/90 and 1893/94, supports this correlation. The extended drought period occurred after the IPO index became *warm* and hence La Niña years or above-average rainfall conditions were less likely to have occurred (Chapter 1). In fact Allan *et al.* (1996a) indicated that no La Niña occurred for the 12–year period from 1894/95 to 1905/06.

Thus, the decade of the 1890s was one of great contrast with an extended period (1889 to 1895) of *cool* IPO conditions including several La Niña years. This was followed by a period (1896 to 1902) with *warm* IPO conditions and intermittent years with negative SOI seasons. Rainfall for western New South Wales reflected these effects. The decade of the 1890s shows a large decline in average annual rainfall from 380 mm for a 5–year period (1889 to 1893), to 277 mm (1894 to 1898), with a further decline to 187 mm (1899 to 1903). The expansion of grazing in western New South Wales had only commenced in the 1870s and was supported by generally above-average rainfall from the late 1870s to early 1890s (Beadle 1948). The abrupt decline in rainfall in the late 1890s was unprecedented in terms of European experience. Not surprisingly the combination of drought and attempts to retain high stock numbers led to the reported devastation.

The unfolding of the drought episode is shown in Plate 2.1. From 1896 to 1898 the drought occurred in the south with northern areas receiving above-average rainfall, but in 1898/99 most of western New South Wales received well below-average rainfall conditions which continued until 1902/03. Because the extended drought period started in the south before the north, we analyse rainfall and stock numbers for both areas of western New South Wales.

The reported stock numbers (Beadle 1948 and Figures 2.1a, b) reflect the impact of these changes in rainfall. The numbers for the south-western Pastures Protection District (PPD) of Wentworth show rapid declines in 1896 and 1897 and again in 1902. In contrast, the rapid decline in stock numbers did not occur in the central northern PPD of Bourke until 1898 and continued to 1900.

Figure 2.1 shows, for five representative PPDs, time series of rainfall (both individual post office data and area–averaged calculations), simulated pasture growth (using 'perennial grass' and 'herbage' parameters, as described in Chapter 2.1) and reported animal numbers.

Stock numbers are taken from Beadle (1948) who converted sheep, cattle and horse numbers to total sheep equivalents. These numbers have been checked with other sources (supplied by R. Richards). N. Abel and A. Langston (CSIRO DWE) have indicated that figure legends in Beadle (1948) for Cobar and North Walgett should have been interchanged. We have confirmed that the relationship between stock numbers and rainfall is more plausible if this error is corrected. We believe that the animal numbers were reported in December, whilst shearing was most likely to have occurred in winter. Pickard (1990) indicated that December reporting underestimated actual stocking numbers which is likely because of sales after shearing.

Estimates of rabbit densities are not readily available but were likely to be highly variable with plagues in the good years and severe reductions in drought (Millen 1899). Pickard (1990) cites estimates of rabbit density for 1891 that effectively doubled the calculated grazing pressure. We have not attempted to include rabbit numbers in the time series. Nevertheless we suggest that the relative stock numbers over the decade plausibly (but conservatively) reflect trends in domestic grazing pressure (e.g. Pickard 1990). Based on the period for stock reporting we have used the annual period January to December in this analysis. The period 1890 to 1894 was used as the base period for comparison of relative trends over time and, with the benefit of 100 years hindsight, is regarded as well above-average (Table 2.1, Plate 2.1). The years 1886, 1887, 1889 were also well above-average (Gibbs and Maher 1967) but have not been included as total animal numbers are not available for comparison.

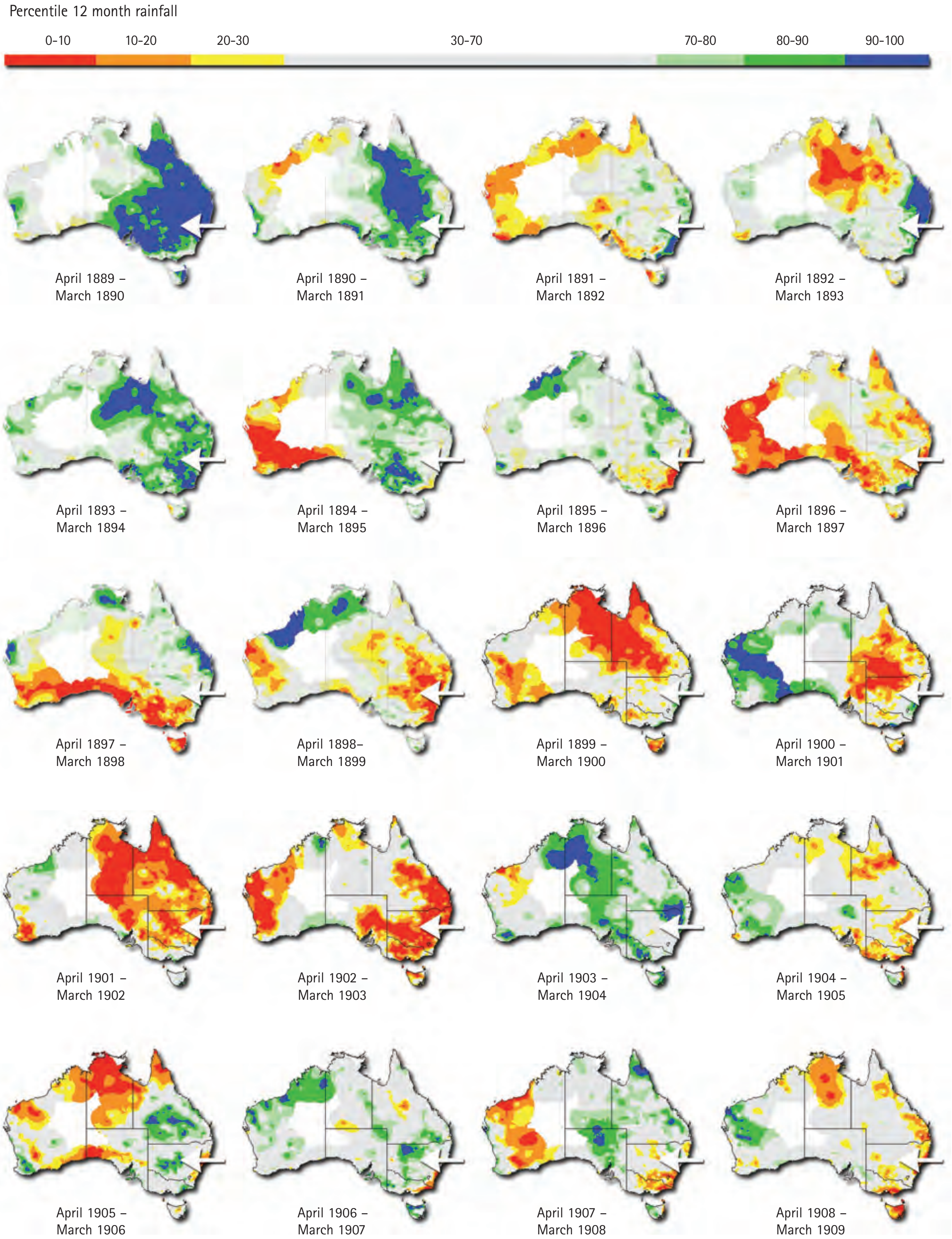
Droughts occurred in 1888 and to a lesser areal extent in 1892. Simulated 'perennial grass' growth was low (60–80%) in 1892 and these effects carried on to 1893. However, stock numbers remained high and in combination with observed 'rabbit plagues' (Noble 1997a) were likely to have exerted heavy grazing pressure (Pickard 1990). In fact one stock inspector reported to the Royal Commission (Anon. 1901, p. 3) that little growth occurred in response to high rainfall in 1891. This apparent loss of perennial vegetation (especially perennial grasses) was to be expected given the heavy utilisation of stock and rabbits.

The start of the drought phase is taken here as 1895 with rainfall at 60–80% of the previous wet period. Simulated pasture growth with 'perennial grass' and 'herbage' parameters was low, 20–40% and 60–80% of the previous wet period respectively. Simulated growth for 'perennial grass' declined to very low levels until 1902 reflecting declining grass basal cover. Simulation with 'herbage' parameters (constant plant density) also indicated low levels of plant growth (40–80% of wet period).

Stock numbers declined during the drought period from 60–100% of the wet period (1890–1894) in 1895 to 20–40% in 1902. Compared to the larger decline in simulated 'perennial grass' growth from 1895 to 1898, stock numbers remained relatively high. Not surprisingly the observations at the time describe: (1) the landscape as in 'deplorable condition' and a 'wasteland' (Millen 1899, Condon 2002, p. 118); (2) near-complete stock losses on some properties (Noble 1997a); (3) large areas of drifting sand; and (4) spectacular dust storms (Condon 2002). Published accounts of major wind erosion events indicated none for the 1890 to 1894 period, four for 1895 to 1899 and two for 1900 to 1904 (McTainsh and Leys 1993).

Episode 1

Western New South Wales 1890-1909



April 1889 – March 1890

April 1890 – March 1891

April 1891 – March 1892

April 1892 – March 1893

April 1893 – March 1894

April 1894 – March 1895

April 1895 – March 1896

April 1896 – March 1897

April 1897 – March 1898

April 1898– March 1899

April 1899 – March 1900

April 1900 – March 1901

April 1901 – March 1902

April 1902 – March 1903

April 1903 – March 1904

April 1904 – March 1905

April 1905 – March 1906

April 1906 – March 1907

April 1907 – March 1908

April 1908 – March 1909

Plate 2.1 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 1. The El Niño years were 1896/97, 1902/03, 1905/06. The La Niña years were 1889/90, 1892/93, 1893/94, 1906/07, 1908/09.

Episode 1A – Western New South Wales 1890s

Time period: 1890 to 1909
Base period: 1890 to 1894

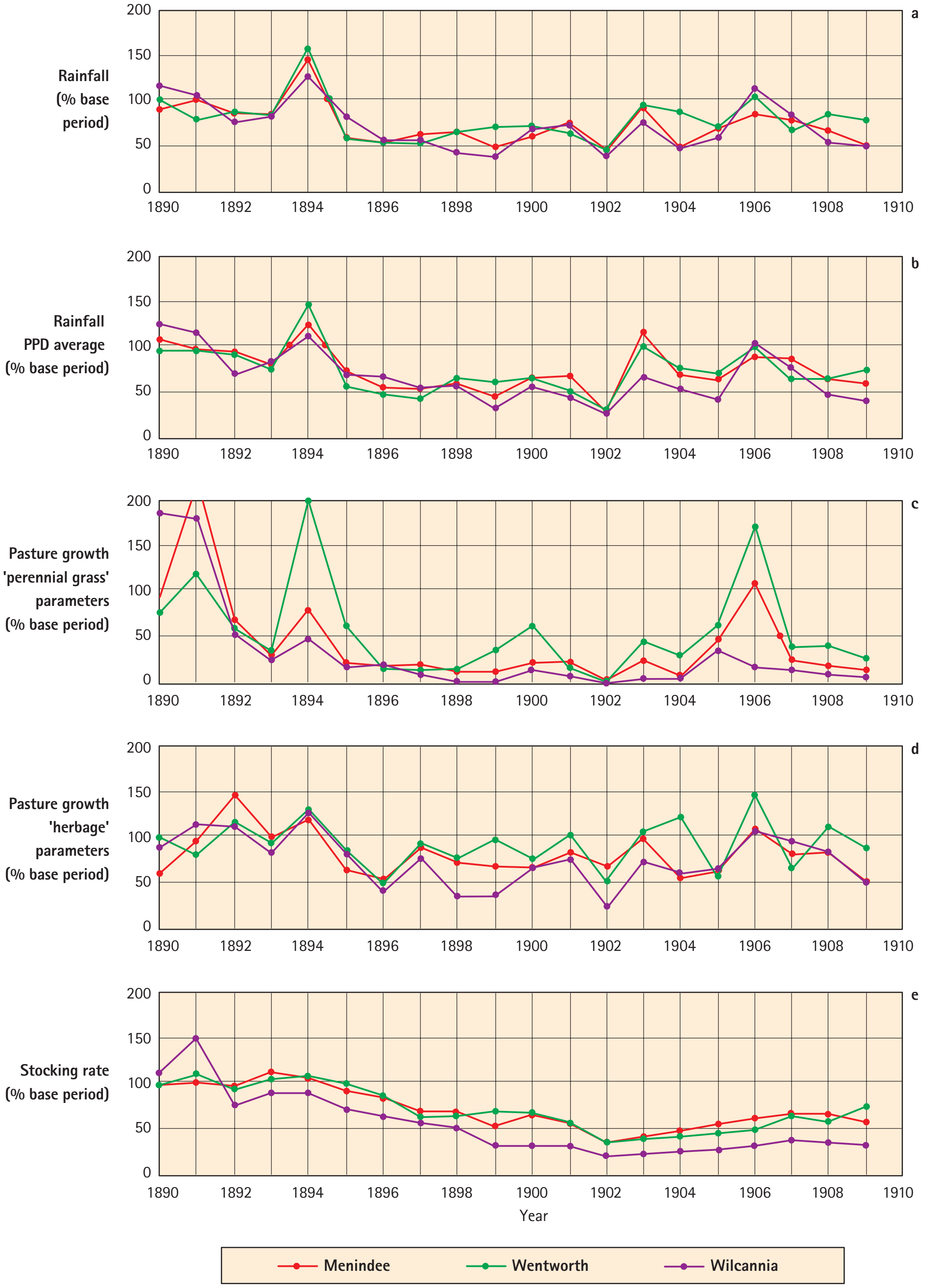


Figure 2.1a Episode 1A for western New South Wales in the 1890s. Time series of: (a) Rainfall; (b) Pastures Protection District (PPD) spatially averaged rainfall; (c) Simulated pasture growth using 'perennial grass' parameters; (d) Simulated pasture growth using Kinchega 'herbage' parameters; and e) Stocking rate. The annual period is 1 January to 31 December. Data are expressed as a percentage of the mean for the base period 1890 to 1894. The year 1895 has been taken as the first year of the consecutive drought/degradation sequence.

Episode 1B – Western New South Wales 1890s

Time period: 1890 to 1909
Base period: 1890 to 1894

Figure 2.1b Episode 1B for western New South Wales in the 1890s. Time series of: (a) Rainfall; (b) Pastures Protection District (PPD) spatially averaged rainfall; (c) Simulated pasture growth using 'perennial grass' parameters; (d) Simulated pasture growth using Kinchega 'herbage' parameters; and (e) Stocking rate. The annual period is 1 January to 31 December. Data are expressed as a percentage of the mean for the base period 1890 to 1894. The year 1897 has been taken as the first year of the consecutive drought/degradation sequence.

Observations and analysis

Detailed observations of the factors leading up to the episode are not available and hence one of the authors (G.M. Cunningham) has constructed a plausible chronology based on his experience in the region:

1. Stock numbers in western New South Wales before 1880 built up gradually due in part to the limited availability of watering points. Much of the country in the 'back blocks', away from major streams, was not used to a great degree until tanks (i.e. dams) were sunk in these areas. This build-up in stock numbers was supported by good rains in the 1870s and the absence of rabbits in many areas.

2. Water development and killing off of the dingo allowed the larger macropod species to multiply, whilst at the same time loss of cover due to grazing contributed to the disappearance of smaller marsupials. Ringbarking of trees also occurred over large areas (mainly in the higher rainfall districts), further increasing the amount of pasture available for grazing. The ringbarking probably produced an initial spike in pasture as a result of the release of nitrogen within the system, which then tapered off.

3. Rabbits arrived at Cobar in the 1880s and quickly spread further north. There was probably, with the arrival of the rabbits, a doubling or tripling of grazing pressure as individual pastoralists held their domestic livestock numbers at the same level as previous years in an endeavour to maintain income. This increase in pressure affected not only the perennial grasses and forbs, but also the more shrubby species that helped maintain livestock in drier times, much as saltbush has been shown to do today.

4. Fire was actively discouraged by high numbers of domestic livestock, rabbits and kangaroos. In the absence of fire, woody shrubs established in selected years with suitable rainfall. This increasing population of woody shrubs then competed with the pastures for water and nutrients.

5. The drought of the 1890s was the 'final straw' that tipped the balance in a situation that was building up gradually but was being masked by good seasons that allowed the annual species (both native and introduced) to produce forage as the perennials declined. In other words, Episode 1 was an 'accident waiting to happen' given the lack of long-term experience of the local pastoralists and community of weather patterns, and a lack of appreciation of the management needs and the persistence capabilities of the native pasture species.

E.D. Millen travelled the Western Division and wrote in the *Sydney Morning Herald* on 18 November 1899:

> It is the land of drifting desert sand and stone-strewn ridges, of open treeless plains, and dense impenetrable scrubs. It is the home of the treacherous mirage, of disappointing salt lakes and fleeting waterholes, of trying winds and exasperating dust storms. It is the stronghold of the rabbit and the most frequent victim of the drought. It is, too, just now a land of buried yards and fences, of abandoned holdings and deserted homesteads, of broad acres, but tragically shrunken flocks. Other districts share these disabilities among them in some degree or taste them in turns; but the fate of the Far West is to drink deep of them all simultaneously.
>
> If my trip had merely revealed what may be regarded as the 'ordinary consequences' of drought there would have been no necessity to write in this strain, or perhaps, to write at all. The ordinary consequences of drought would disappear with the return of a generous season. But in the creation of the conditions now observable in the Far West, the drought is but one of several contributing causes. Its temporary disappearance alone will not suffice to tide over the crisis at which I conceive the Western grazing industry has arrived. Not that the drought has been less virulent than is generally recognised. It is unquestionably the severest visitation of its kind with which the settlers have had to contend. Not in one district, but in several, there is evidence that it has been the worst since the settled occupation of the country. It is indeed hardly possible to exaggerate the severity and effects of the prolonged and still unbroken drought. It has been widespread, remorseless, prolonged.

Beadle (1948, p. 83) 50 years later with extensive experience of the droughts of the 1940s provided a detailed analysis of the impact on stock numbers:

> From 1879 to the early nineties of last century the number of sheep both for the whole State and the Western Division was gradually rising; the maximum for both State and Western Division occurred in 1891. At this time the Western Division supported 15.4 million sheep, the total for the State being 61.8 million, i.e. in the year 1891 when the west was carrying its maximum stock-population it supported 25% of the sheep depastured in the State. At this time the west was hopelessly overstocked and it was during the next ten years that the reserve of perennial fodder-plants was exhausted and the soil erosion was initiated.
>
> After the great drought of 1901–2 the Western Division stock-population dropped to 3.5 million. Since this date figures have risen slightly, though the graph is a series of peaks and depressions which indicate that the pastoralists are dependent largely on annual species and that the perennial reserves had never been built sufficiently high to support a constant stock population.

Beadle (1948, p. 85) further observed that:

> In 1902 the stocking rates had reached their minimum, though in a few cases lower values were recorded later. From 1906 to 1910 there was a series of average to fair seasons throughout the west and as a consequence the number of stock increased, giving a second peak about the years 1910–12. This peak, however, was far below the high values of 1891. Consequently, it seems most probable that during the drought of 1902 most severe pasture deterioration was experienced and that in spite of the more favourable conditions during 1906–1912 regeneration of perennials did not occur.

R. W. Condon (pers. comm.), commenting on the run of favourable seasons from 1906 to 1912, suggested that substantial pasture degradation occurred on the soft and hard loamy red earths due to *Aristida jerichoensis* (and other Aristidas in the mulga sandplains further west) replacing all the 'soft grasses, and becoming super-abundant. *A. jerichoensis* was just about unusable and virtually half of the Western Division would have been dependent on annuals between wire grass tussocks, the ground protected by the [wire] grass'.

Thus both first-hand observation and analysis of reported rainfall change and stock numbers confirm the severity of the drought, the heavy grazing pressure on the resource, and the evidence of the degradation processes of loss of 'desirable' perennial species and soil erosion.

Millen (1899) in his articles directly addressed the causes of degradation:

> In the pre-settlement days though the drought raged and the wind blew, there were bushes that defied the one and checked the other, while the roots of the dead grass remained so steady and hold the soil together.
>
> But with the advent of stock and rabbits, these counteracting forces have been removed. The destruction of the bushes has left the wind without check or break, the destruction of the roots (for which the rabbits must be held principally responsible) has left the soil hopelessly at its mercy, while the constant traffic of stock served to still further loosen and disintegrate a soil, invariably friable and frequently little more than pure sand.

A subsequent editorial called for a Royal Commission that was appointed in August 1900 and reported on 5 October 1901 (Noble 1997a). In his seminal book 'The Delicate and Noxious Scrub', Noble (1997a, p. 20) summarised the Commission's findings regarding the causes of the 'unprofitability' of the pastoral industry throughout the Western Division of New South Wales:

> In listing the 'Causes' of the widespread depression and general unprofitability of the pastoral industry throughout the Western Division, the Royal Commission report identified seven principal factors. All seven were related, in different ways and varying degrees, to increased scrub levels:
>
> *low rainfall* – '.... The frequent subjection of the country to periods of drought may fairly be regarded as the primary and most constant cause of the difficulties which beset the western grazier'

> *rabbits* – '.... The pastoralist had been for many years under the unavoidable necessity of expending annually, in his attempt to cope with the pest, sums of money, which, unexpended, would in many instances have represented a substantial profit in a year's operations'
>
> *overstocking* – '.... The opinion [is] very generally that in the early days of settlement in the Western Division much too favourable a view was taken of the carrying capacity of the country'
>
> *sand-storms* – '.... The vegetation on the face of large areas of the drought-stricken country had been destroyed, causing 'calamitous sandstorms', which had converted hundreds of thousands of acres of country into dust bowls. On 'Teryawynia' Station at Wilcannia, 100,000 acres out of a total of 460,000 acres were 'as bare as a floor', in spite of [the] great rain which they have had'
>
> *growth of non-edible scrub* – '.... A great deal of evidence from lessees in the eastern portion of the Division was furnished, which goes to show that in that part of the Western Division the carrying capacity of large areas had been greatly reduced by the spread of non-edible scrubs'
>
> *fall in prices* – '.... [the] decline in the prices of pastoral products has, of course, cut down the profits of the industry far below what they formerly were, and has correspondingly limited the power of tenants to cope with the natural difficulties of the country'
>
> *want of sufficient area* – '.... Whilst sharing in common with the larger holder the difficulties appertaining to the western country, the homestead lessee has laboured under an additional disability, namely, being limited by law to an area insufficient over the greater portion of the Division to afford anything like an adequate means of subsistence.

High stock and rabbit numbers during the early 1890s (e.g. Pickard 1990) were likely to have severely reduced perennial plant density without sufficient recovery in 1894. Hence the resource was already in poor condition going into the extended drought period 1895 to 1902. However, animal numbers did not decline to levels needed to match pasture growth ('perennial grass' simulation) until several years into the drought period. For example, at Tindarey Station at Cobar, sheep numbers were 70,000 in the first year of drought (1897) and declined rapidly to 5,000 in the third year (1899) (Noble 1997a).

Several reasons have been advanced for the apparent reluctance of graziers to reduce stock numbers in the drought period. The mid 1890s was a time of financial crisis. Wool prices declined by >30 % from 1890 to 1895 (Barnard 1958). Heathcote (1965 p. 155) calculated that by 1901 expected gross income was a third of that in 1891. Condon (2002, p. 382) states that 'most of the pastoral runs were in the hands of the pastoral finance companies, which had acquired them by mortgage. Their primary objective was profit for shareholders with maximum profit for minimum expenditure'. This resulted in little money for development, especially of watering points, and hence inevitable concentration of stock on a limited number of permanent watering points. Condon (2002, p. 382) suggests that managers who contemplated reducing stock numbers were likely to be replaced 'for daring to hold such "idiotic" concepts'. The other factor recognised later by Western Lands Commissioners was the lack of transport to move stock, and hence their advocacy for railways and well-maintained public stock routes.

Beadle (1948) reviewed the long-term impact of this episode as well as subsequent droughts (late 1920s and 1930s). He compared the two periods 1890 to 1899 and 1931 to 1940 in terms of stock numbers and indicated for each PPD the change in stock numbers and degradation features (Table 2.2). Although the periods differed in average rainfall (e.g. 300 mm/year compared to 241 mm/year for the Western Division) the 1890s average is strongly biased by the first 2 years, and averages for 1892 to 1901 and 1931 to 1940 are similar (247 compared to 241 mm/year). Thus the decrease in stock numbers, especially in north-western New South Wales (–40 to –70%, Table 2.2), is greater than would be expected due to rainfall alone (–20%) and hence cannot solely be attributed to rainfall differences.

Beadle (1948) found that the decline in stock numbers (Table 2.2) was strongly correlated with overall long-term variability of rainfall (i.e expressed as % average deviation). Beadle's analysis, which integrated the net result of degradation and recovery processes from 1890 to 1940, indicated that the continual attempt to run flocks and herds without large changes in year-to-year stock numbers inevitably put pressure on the resource. His analysis suggests that the greater the climatic variability, the greater was the risk of degradation.

With the benefit of hindsight and a hundred years distance we suggest that the favourable climatic period 1889 to 1894 biased expectations of carrying capacity. The damage being done by rabbits and the 1892 drought was masked by subsequent rain in 1893. The sequence of drought years from 1895 (south) or 1897 (north) (Figure 2.1) onwards was beyond expectations or previous experience. Coupled with economic woes the reduction in stock numbers required to prevent damage was not managerially possible or may not have even been successful given the inability to control total grazing pressure.

Table 2.2 Comparison of stock numbers for the decades 1890 to 1899 and 1931 to 1940 reproduced from Beadle (1948, page 85).

Pastures Protection District	Mean annual number of sheep equivalents ('000)[1]		Percentage change	Notes on pastures and erosion
	1890–99	1931–40		
Balranald	540	505	- 6.5	Replacement of saltbush by copper burrs. Sand dunes local.
Bourke	2,400	1,149	- 52.1	Timber death. Removal of Mitchell grass and saltbush. Scalding and dunes.
Brewarrina	1,348	678	- 49.7	Removal of Mitchell grass and saltbush. Scalding.
Cobar	1,309	783	- 40.2	Timber death. Increase in wire grass. Sheet erosion and scalding.
Hillston	1,249	893	- 28.5	Replacement of saltbush by copper burrs. Scalding.
Menindee	998	590	- 40.8	Replacement of saltbush by copper burrs. Scalding.
Milparinka	796	250	-68.6	Timber death. Dominance of wire grass. Loss of saltbush. Increase in copper burrs. Loss of Mitchell grass. Dunes and scalding.
Walgett & Walgett North	2,160	1,705	- 21.6	Decrease in Mitchell grass. Scalding.
Wanaaring	949	430	- 54.7	As for Milparinka
Wentworth	561	521	- 7.1	Decrease in saltbush. Increase in copper burrs. Local dunes and scalding.
Wilcannia	1,673	735	- 56.1	As for Milparinka
Canonba [sic.]	1,565	1,416	- 9.5	Increase in wire grass. Scalding
Condobolin	1,672	1,759	+ 5.2	Increase in wire grass. Scalding
Deniliquin	1,474	971	- 34.1	Decrease in saltbush. Increase in copper burrs. Scalding.
Hay	1,634	1,313	- 19.6	As for Deniliquin
Moulamein	748	634	- 15.2	As for Deniliquin
Narrandera	1,400	1,393	- 0.5	As for Deniliquin

[1] Cattle and horses converted on the basis of being equivalent to ten sheep.

Recovery?

Above-average rainfall in 1905/06 and 1906/07 in combination with reduced stock numbers and probable reduction of rabbit populations would appear to have resulted in some recovery. However, we have already referred to Beadle's analysis (Beadle 1948, p. 85) suggesting 'regeneration of perennials did not occur'.

The commissioners for the Western Land Board wrote on 1 August 1907 (p. 63) to the Secretary of Lands as follows:

> The year generally has been one of marked prosperity in the Western Division.
>
> Improved conditions brought about by the unusually long continuance of seasons of greater and more regular rainfall, coupled with the high values of pastoral products, are well maintained and the prospects of a continuance of these conditions appear to be favourable.
>
> The number of stock has increased from about 3,500,000 sheep, in 1902, to 6,269,000 sheep at the end of 1906, and during this period the area of unoccupied lands has been reduced from 3,762,176 acres to 1,266,482 acres.
>
> The pasturage has wonderfully improved, but not to such an extent as would justify the country being stocked up to anything like its former carrying capacity, and it is safe to say that a drought of even short duration – unless a minimum quantity of stock is carried – will quickly reduce the country to the same condition as it was during the droughty period preceding 1903, during which the edible scrubs were almost destroyed, and in consequence of the absence of surface protection the greater part of the Western Division was one bed of drifting sand.
>
> The photographs, herewith, taken last summer show that the sands are still moving.
>
> The condition of drifting sands will periodically occur, and the areas probably increase upon the recurrence of drought until railways are provided to enable stock to be removed at the critical times; it is in failing seasons the damage is done, when large numbers of stock are kept on the land, simply because they cannot be removed.
>
> From 1902 to 1906, both years inclusive, there were no effective means to compel all landholders in the Western Division to destroy rabbits; although lessees under the Western Lands Act were compelled to take certain measures for the destruction of the pest, other landholders were exempt. This led to a most unsatisfactory state of affairs; but the Pasture Protection Amendment Act of 1906 now places, subject to certain limitations, all landholders in the Western Division on the same footing as those in other parts of the State. Beneficial results are confidently expected.
>
> The rabbits generally have not been so numerous as it was feared they would be at the date of last report, the lessees apparently having fully realised that the pest can generally, and at a small cost, be kept within reasonable bounds. In the better part of the Division large quantities of rabbit and dog proof fencing have been erected.

What do we learn for preventing land and pasture degradation?

1. In 1907 the commissioners wrote with great insight as to the condition of resource, the causes of degradation, and the actions needed to prevent degradation. Other annual reports in this period (1903 onwards) show great enthusiasm for, and commitment to, protection of the valuable natural resource. However, the physical, biological and political forces that led to further degradation episodes were not within their control. Thus we learn that enthusiasm and commitment alone are not sufficient to prevent degradation.

2. Some graziers are unlikely to take pro-active decisions to reduce stock numbers unless economic viability is assured, and warnings/forecasts before and at the start of the episode are readily available.

3. In north-western New South Wales there were few long-term climatic records and hence limited appreciation of what could occur in terms of extended wet and dry periods. The strong and consistent effects of ENSO through Episode 1 support the hypothesis that seasonal forecasting can provide some season-by-season warning of dramatic climate fluctuations.

2.3 Episode 2: North-eastern South Australia and western New South Wales in the 1920s and 1930s

The 1920s continued the boom and bust cycle of the pastoral industry in South Australia and western New South Wales (Donovan 1995). Record quantities of wool were offered at the Adelaide wool sales in 1926 (Donovan 1995, p. 70). The South Australian pastoral industry was mainly concerned with the impending expiration of pastoral leases and called for a Royal Commission in 1926. From 1926 to the late 1940s there were severe and extensive droughts. The deterioration of the pastoral lands was readily apparent and led to the establishment of a Soil Erosion Committee chaired by the Council for Scientific and Industrial Research scientist, Francis Ratcliffe, who documented his findings in research papers (Ratcliffe 1936, 1937) and in the book 'Flying Fox and Drifting Sand' (Ratcliffe 1970, first published 1938). Legislative action followed with the *Soil Conservation Act 1939* that 'amended the *Pastoral Act* by reducing the minimum stocking rate where land was considered at risk of degradation and setting maximum stocking rates instead' (Donovan 1995, p. 83).

Climate history

Table 2.3 and Plate 2.2 show the 20-year period from 1919/20 to 1938/39 for North East District, South Australia and neighbouring western New South Wales, spanning the major extended drought period from 1925/26 to 1929/30 common to both regions. In South Australia prior to the extended drought period there was average rainfall with some significant dry years, e.g. 1919/20, 1922/23. Similarly western New South Wales was in severe drought in 1918/19 (not shown) and 1919/20 with mostly average years up to 1925/26. In both regions, 1922/23 was a major drought year, but in western New South Wales it occurred between two average years reducing its impact.

In both regions extreme rainfall deficiencies occurred in 1928/29 and 1929/30 following two previous years of below-average conditions. Intermittent years of severe droughts continued through the 1930s. During the 20-year period there were three La Niña years which produced average to above-average rainfall (1921/22, 1924/25, 1938/39). There were four El Niño years (1919/20, 1923/24, 1925/26, 1932/33), with two of these years (1919/20 and 1932/33) having substantial rainfall deficiency in both regions (–25% to –57%).

Table 2.3 Extended drought period (brown) during regional degradation Episode 2 in North East District, South Australia and western New South Wales. The extended drought periods were calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12-month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought periods were the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5). Years in the table are indicated only by the starting year, i.e. 1919 is the period 1 April 1919 to 31 March 1920, referred to in the text as 1919/20.

a

Episode	Rainfall Anomaly										
Episode 2 North East District, SA	Year	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
	% Anomaly	-25	+130	-20	-40	-16	-7	-43	-6	-28	-59
	Year	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938
	% Anomaly	-36	-4	-8	-34	-12	-42	-22	+38	-15	+22

b

Episode	Rainfall Anomaly										
Episode 2 Western NSW	Year	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
	% Anomaly	-57	+54	-3	-52	-2	+7	-5	-29	-13	-64
	Year	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938
	% Anomaly	-44	+12	+29	-34	+4	-26	+4	+8	-61	+1

In terms of regional rainfall for North East District, South Australia, the period 1932/33 to 1935/36 also constitutes an extended drought period. The period was likely to have exacerbated the resource damage that occurred in the mid to late 1920s. The evidence of resource degradation during the mid 1930s supported the need for changes in management and government policy in South Australia (e.g. Ratcliffe 1970, Donovan 1995).

In a recent formulation of the IPO 'index' (September 2002), the index was *cool* from 1907 to 1920 becoming *warm* during the 1920s. However, earlier formulations and alternative measures, such as the PDO, indicate the change from *cool* to *warm* was later in the 1920s. For example, Mantua and Hare (2002) indicated that the PDO pattern switched to the *warm* phase in 1925 at the start of the extended drought period.

The 11–year period from 1925/26 to 1935/36 was generally average to below-average with widespread drought in the three consecutive years 1927/28, 1928/29, 1929/30. More importantly there was no occurrence of a year with substantially above-average annual rainfall during the 11 years of the dry period, and hence no opportunity for sustained regeneration of vegetation or relief from grazing pressure. Ward and Russell (1980) identified the period of the 1920s as one of a change in the behaviour of high pressure systems. They indicated that a greater development of anti-cyclones in the 1930s was likely to have occurred. Whilst this analysis supports the view that changes occurred in the climate forcings during this period of severe drought and high frequency of dust storms (Ward and Russell 1980), a more mechanistic understanding of year-to-year variability in rain and extreme wind events is still the subject of research.

Data sources and chronology

A conservatively stocked property, Mutooroo (Mutooroo Pastoral Company, Anon. 1951), in South Australia, and the adjoining New South Wales PPD Menindee, have been used to evaluate the episode (Figure 2.2). The period January to December was used to align with PPD animal numbers. Pasture growth was simulated with 'herbage' parameters derived from data collected near Menindee. Animal numbers are sheep shorn reported for Mutooroo (Anon. 1951) and stock numbers reported for Menindee (Beadle 1948).

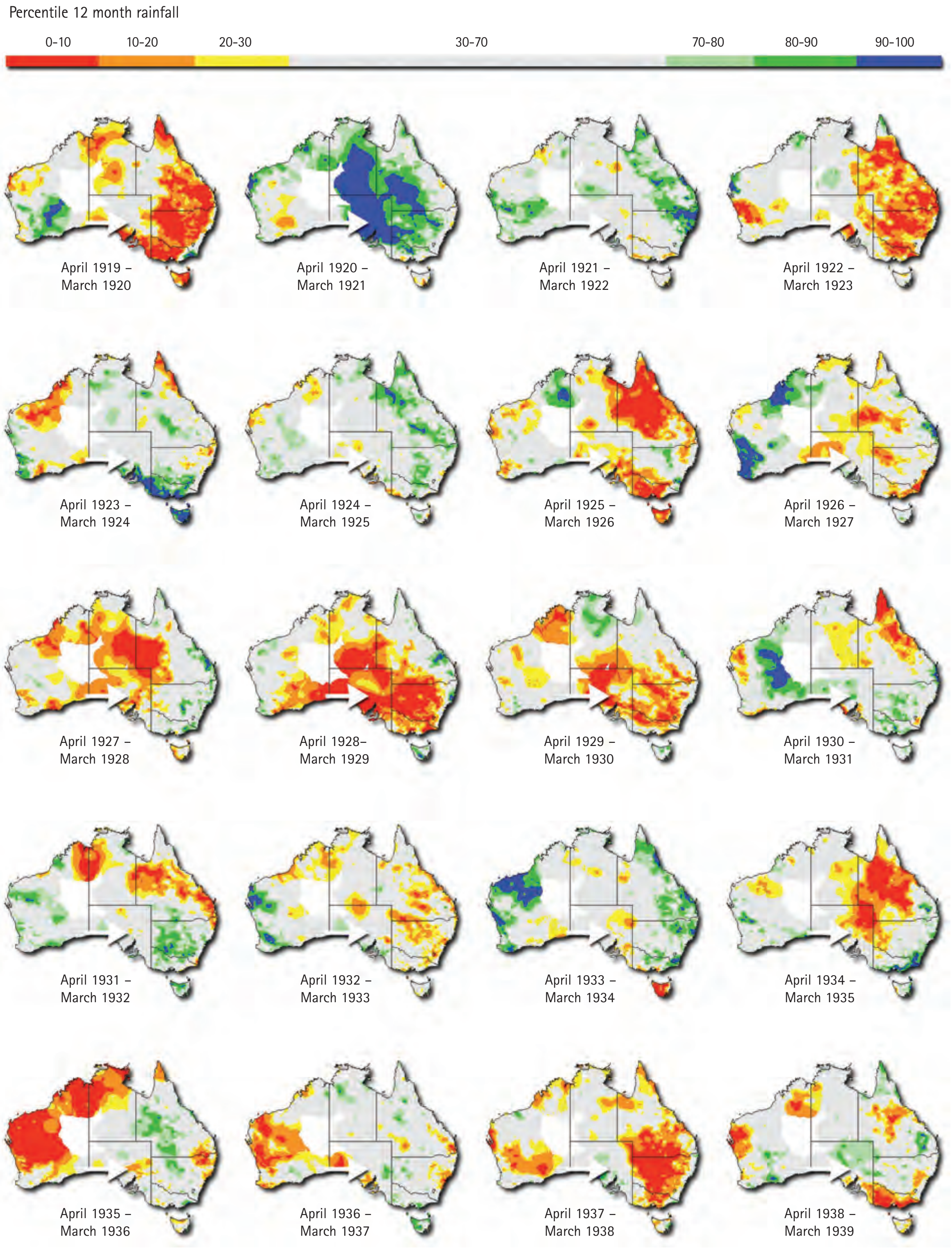
The 10–year period from 1917 to 1926 was chosen as the base period for relative time-series. Both property and PPD rainfall had similar relative patterns over time although there was variation from 1929 to 1931 resulting in greater differences in simulated pasture growth.

The base period in the mid 1920s at Menindee included two droughts 1922 and 1924 in which simulated pasture growth was 40–50% less than the average for the wet period. The drought period 1927 to 1929 began with an extremely severe drought in 1927 especially in terms of simulated pasture growth (0–25% of the previous wet period). At Mutooroo subsequent years were also low, 60% and 10% of the base period for 1928 and 1929, respectively. The year 1930 was not as severe in Menindee as at Mutooroo. Similarly years of low growth occurred again in 1935 in these regions.

Three major wind erosion events are documented in the period 1925 to 1929 reflecting the wide expansion of the drought in Queensland and New South Wales as well as South Australia. None were reported in the period 1930 to 1934 but four events were reported in 1935 to 1939 reflecting widespread drought and resource damage (McTainsh and Leys 1993).

From 1927 onwards, stock numbers declined to 80% of the previous base period. At Mutooroo there was a substantial increase in sheep deaths from average 4,460 (4% of sheep shorn) in 1927 to 9,974 (8%) in 1928 and 18,506 (19%) in 1930, reducing to 2,012 in 1931. It is not clear which seasons the deaths were actually associated with but they do show the impact of the drought and the likely grazing pressure on the landscape even for this conservatively stocked property. Substantial increases in sales were also reported from 1926 to 1929. Other reports indicated that grain feeding of stock was thought to have become common practice in

Episode 2
North-eastern South Australia and western New South Wales 1920-1939



April 1919 – March 1920

April 1920 – March 1921

April 1921 – March 1922

April 1922 – March 1923

April 1923 – March 1924

April 1924 – March 1925

April 1925 – March 1926

April 1926 – March 1927

April 1927 – March 1928

April 1928– March 1929

April 1929 – March 1930

April 1930 – March 1931

April 1931 – March 1932

April 1932 – March 1933

April 1933 – March 1934

April 1934 – March 1935

April 1935 – March 1936

April 1936 – March 1937

April 1937 – March 1938

April 1938 – March 1939

Plate 2.2 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 2. The El Niño years were 1919/20, 1923/24, 1925/26, 1932/33. The La Niña years were 1921/22, 1924/25, 1938/39.

Episode 2 – North-eastern South Australia and western New South Wales

Time period: 1917 to 1939
Base period: 1917 to 1926

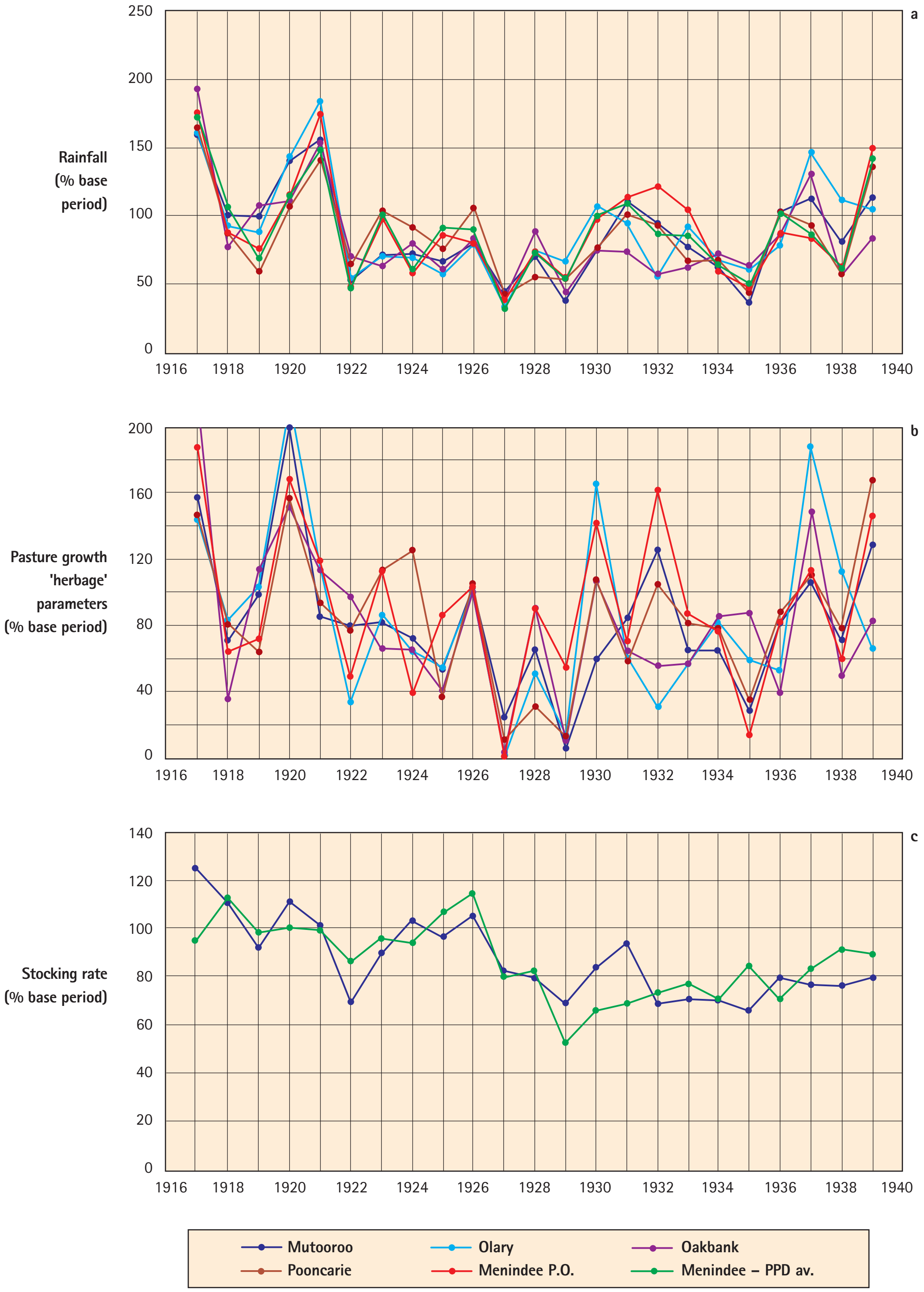


Figure 2.2 Episode 2 for South Australia and western New South Wales in the 1920s and 1930s. Time series of: (a) rainfall (five stations and spatially averaged for Menindee PPD); (b) simulated pasture growth using Kinchega 'herbage' parameter set (five sites); and (c) reported stock numbers (Mutooroo and Menindee only). The annual period is 1 January to 31 December. Data are expressed as a percentage of the mean for the base period 1917 to 1926. The year 1927 has been taken as the first year of the consecutive drought/degradation sequence.

late 1929 (Donovan 1995). The policy of Mutooroo management of conserving 'bush and scrub country' for drought feeding successfully allowed survival of breeding flocks through the severe droughts (Anon. 1951).

The comparison of stock numbers for Mutooroo, as a conservatively stocked station, and the neighbouring New South Wales PPD (Menindee) shows differing impacts of drought. Despite the greater severity of the drought at Mutooroo, especially in 1928 and 1929, there was a smaller decline in stock numbers than in Menindee PPD in 1929 (down to 50% of pre-drought numbers).

During this time, prices for wool declined, virtually halving from 1927 to 1931 (Payne and McLean 1939). This decline compounded the previous rapid fall in May 1925 when prices declined by 25%. As a result, wool prices in 1927 were approximately two thirds of 1924 prices and 1931 prices were only one third of the 1924 prices (Figure 1.4). Thus the severity of the drought and the low prices were a 'double blow' to graziers. This possibly contributed to a reluctance of graziers to reduce numbers in Menindee. In contrast, it was stated that animals were sold from Mutooroo in response to drought irrespective of declining prices (Anon 1951).

Observations and analysis

The following brief summary of the unfolding of the episode has been drawn from a variety of sources (Foley 1957, Donovan 1995).

Foley (1957, p. 167) made the following notes on the drought in South Australia and western New South Wales including references to dust storms and condition of the country.

For South Australia he noted:

> In 1925 severe drought conditions were experienced in the far north and north-west interior. Some stations recorded less than half the normal rainfall for the year. The drought continued until March 1926 when good rains fell.
>
> The year 1927 was very dry practically throughout the pastoral country. The year was the driest on record to date in the Upper Murray and adjacent districts.
>
> In 1928 severe drought prevailed over most of the pastoral areas during the greater part of the year which was the driest on record to date in parts of South Australia and the Northern Territory. In November 1928 it was reported that the greatest drought in the history of the Upper Northern Country ravaged the land. The plains of Pinda, Hammond, Willochra and Boolcunda were 'a dust heap'. Around Quorn 20,000 acres of wheat were sown but 'few would get their seed back'. Sheep were being hand-fed. At Hawker practically no crops had been grown for the last three years and farmers had to 'get rid' of sheep.
>
> Frequent severe dust storms occurred during the latter part of the year.
>
> Drought conditions continued over the pastoral country in 1929 as well as in the north-west of New South Wales and south-west of Queensland. It was the driest year on record to date at a few stations in the Upper North.
>
> In July 1929 stock in the Innamincka district were struggling for existence. At Cordillo Downs 33,000 sheep were shorn as against 51,000 in the previous season.
>
> A traveller in the north-east in November in 1929 reported that the last five years had been most trying. Everywhere on his journey sheep were dead or dying. There was no herbage. Dust storms which were unknown in good seasons occurred almost daily causing the deaths of thousands of sheep. Sand in the wool weighted the sheep down and they were covered by drifts.

For New South Wales he noted (p. 70):

> In August 1927 a party motoring from Adelaide to Winton, Queensland via Broken Hill reported that the country was bare of feed from Broken Hill to Wilcannia. Most sheep in the Wilcannia district were away or were

> artificially fed. From Wilcannia to the Paroo the country was in a very bad state. Cattle were dying between the Paroo and Wanaaring and similar conditions prevailed from Wanaaring to Hungerford and Thargomindah (Queensland).

Donovan (1995, p. 75) cites the evaluation by J.N. McGilp, the President of the Stockowner's Association, (S.A.) in 1929:

> Stock on the pastoral country had been so seriously depleted in numbers until it was questionable whether there were 25 per cent of the number carried in normal seasons now depastured outside of Goyder's line. The seriousness of the position would be realised when it was remembered that 3,300,000 sheep were normally carried in that territory.

In 1932 conditions were very dry in the north-east of South Australia. Large areas of pastoral land were offered to the public but there was poor response due to poor economic and climatic conditions (Donovan 1995). By 1934 the Board was convinced of the need for larger leases in order to achieve more sustainable management and took steps to increase the size of some leases. A report in the *Advertiser* stated that 'saltbush and other herbage have disappeared entirely in many parts' (Donovan 1995, p. 81). In 1935 the majority of cattle stations in north-eastern South Australia were carrying no stock at all and many had been deserted (Ratcliffe 1936 p. 41). Claims were made that the far-northern pastoral country of South Australia was reverting to desert – carrying capacity was down by 75% since 1920, shearing down by a third and described as being in the worst condition for thirty years (Tolcher 1986). Heavy winter rains 'broke the drought' and caused the great inland rivers to come down in flood (Ratcliffe 1970, p. 287), probably indicating a lack of surface cover.

The apparent degradation in the form of frequent dust storms continued to occur during the 1930s (Ratcliffe 1970). C. Goode reported (J. McDonald pers. comm.) some recovery on a few leases from 1935 to 1937. Though mainly the growth of annuals, it included regrowth or appearance of perennials in a few instances. Some places did not recover even by 1938, showing improvement only through the exceptional rainfall of 1939.

A South Australian Royal Commission had been called for in 1926 before the drought, concerning the impending expiration of pastoral leases in some 12 to 18 years in the future (Donovan 1995, p. 69), although concern was also being expressed on the use of the grazing resource.

> The deputation called for a Royal Commission into the industry, to enable the industry to outline its concerns and to provide a further opportunity to lobby for freehold tenure, or at the least perpetual leasehold, of the pastoral country. J.E. Kirk, the spokesman for the deputation, reasoned:
>
> 'that any system which was to terminate the leases in 21 or 42 years would have the effect of inducing the lessees to use the country to its fullest possible extent, irrespective of the damage that might be done to its future productivity. Every man who held a pastoral lease to-day was going to get all he could out of it. To make the best of saltbush country a good deal of money had to be spent in improvements, and few pastoralists felt prepared to spend substantial sums when they knew they were going to lose the land at the end of the lease. They thought the land should be in perpetuity. In fact, the best system would be the covenant to purchase, which would give the owner an inducement to nurse the land and improve it if possible. By carefully spelling the country at times they would allow the saltbush to come back, and it was in the interests of the State that this should be done.'

Amendments to the pastoral legislation in 1929 established a new Pastoral Board and provided new 42–year leases giving some certainty to pastoralists in financial planning as the low wool prices of the 1930s must have been a concern.

Donovan (1995) in his history of the Pastoral Board of South Australia does not refer to any explicit observations of degradation until 1932 (in South Australian Parliamentary Papers) and early 1934 in printed

media (*Advertiser*). However, the likely impact of drought and grazing on the resource was evidenced by: (a) anecdotal observations of sand drift (R. Tynan pers. comm.); (b) lease reports in 1928 (J. McDonald pers. comm.); (c) documented soil erosion on a continental basis (McTainsh and Leys 1993); (d) reports that graziers fed grain to sheep in spring 1929 (Donovan 1995 p. 75); and (e) reported increase in deaths even at conservative stocking (Anon. 1951).

In the early 1930s, concern was expressed that, despite good rainfall (Figure 2.2), the land appeared to be recovering only slowly. Thus, although the period 1931 to 1932 had conditions of adequate rainfall for pasture growth (Figure 2.2), the return of drier conditions in 1934 and 1935 raised considerable alarm in terms of resource degradation. Ratcliffe (1970, p. 188) was commissioned to survey the problem for the Council for Scientific and Industrial Research in 1935. We refer to Ratcliffe (1970) as the source of our quotations, although the reader should recognise that much of this material was reported in his research papers in 1936 and 1937 (Ratcliffe 1936, 1937). He describes his charter as given to him by Professor A.E.V. Richardson.

> You are a biologist. It is quite on the cards that the problem will turn out to be a purely biological one, hingeing on the rabbit. In that semi-desert country rabbits breed up to plague numbers every few years, and are very destructive to the vegetation. It is the disappearance of the plants that has allowed the wind to work on the soil, causing it to drift. If you take on the job, all you will be expected to do is to define the problem. That is often half the battle. When we know exactly what is happening, and why it is happening, we should be able to decide whether the solution lies with botanists or soil experts, whether it must depend on the control of the rabbit, or is fundamentally a question of stock management.

From his extensive field survey in 1935, Ratcliffe (1970, p. 196) describes the main mechanisms of degradation, thus:

> I had read a lot, and seen a little, of the recent drought in western Queensland, during which millions of sheep had perished. I was therefore rather surprised to discover that sheep were not dying, and had not died, wholesale in South Australia, which had apparently suffered an equivalent reduction in rainfall. The explanation of this seemingly topsy-turvy state of affairs – of almost-desert proving safer in a drought than a region with about twice its rainfall – is purely botanical. The plains of western Queensland are grass country, and grass will lose its nutriment, rot, and blow away in a relatively short time. South Australia, on the other hand, possessed in the perennial saltbush and bluebushes a reserve supply of fodder which would only disappear as it was eaten.
>
> The fact that the 'bush' had been eaten too much during the lean years when other feed had failed turned out to be the key to the problem of drift and erosion. Over-grazing had killed and destroyed the bush over thousands of square miles of country; and when the plant cover had disappeared, the soil lay unprotected at the mercy of the wind.

Ratcliffe (1970, p. 317) addressed the issue of how to manage grazing in this environment:

> Was there *any* system of stocking and management, workable and economic in practice, that would preserve the vegetation of the semi-desert country, and thus ensure the survival of human settlement in these areas? This was the question that kept hammering in my head. Worry and puzzle as I might, I could see only one answer; and it was not the answer I wanted or had hoped to find.

He formulated the problem as a 'mathematical rider' and sought to simplify the problem 'into an equation with certain natural and certain humanly controllable factors as the constants and variables' (p. 318). He listed the following factors which we report in depth because of their remarkable insight:

1. The number of sheep carried is 'determined by local custom, tempered by experiences and financial considerations' (p. 318). The latter determined the minimum number of stock to be viable.

2. Varying stock numbers with changing seasons 'is only practised, voluntarily, to a limited extent'. He asserted that 'nine sheepmen out of ten will, therefore, take any gamble rather than break up their breeding flocks' (p. 318).
3. Grazing had little impact on short-lived annual and ephemeral plants and mature [dormant] perennial grasses but evergreen bushes and shrubs 'can easily be killed by over-grazing in drought' (p. 319). The apparent susceptibility of some shrubs to drought in the absence of grazing indicated 'how small is the margin of vigour they have in reserve' (p. 319).
4. Rate of regeneration of long-lived woody plants was slow with rabbits contributing to the problems of seedling survival.
5. Severe droughts are frequent and 'it would be more accurate to say that good seasons are the exception, drought the rule'. Ratcliffe (1970, p. 320) asserted that 'the Australian inland must expect a smashing drought once every decade and lesser droughts more often'.

J. McDonald (pers. comm.) is currently reviewing the historical inspection reports made in the 1930s by C. Goode, Inspector of Pastoral Leases and Supervisor of Boring. C. Goode concluded that overgrazing was the problem and not drought. He was able to convince some lessees to spell badly affected areas. However, some lessees did not have the required patience. C. Goode also provided accounts of how drought affected good bush cover and stated that it took five years, even under favourable seasons for recovery to occur.

Stocking rates

Ratcliffe (1970) cited successful examples of where graziers, using low stocking rates (half of what was 'universally' regarded as 'light stocking'), had saltbush in good condition in 1935 whilst neighbouring properties had stocked too heavily and the country was showing the effects of erosion and 'leafless vegetation'. The paddocks in good condition were carrying 'as many sheep as it was safe to put into them without endangering' [the saltbush] (p. 321).

Others supported the need for low stocking rates, and hence a halt to subdivision of the big leases (Pick 1942, p. 46): 'The big stations may be, and undoubtedly are, partially denuded of bush, but the small holdings are, almost without exception, eaten right out'.

R. Condon (pers. comm.) has provided the following view for western New South Wales:

> The basic problem for the small holders, certainly in western NSW and probably also in South Australia, was that the holdings were much too small. The otherwise insightful Western Lands Commissioners were making land available in 10,240 acre blocks (enough to run 600 sheep in most of the West Darling country). These holdings often came back to the pastoral leases after being devastated by drought and overstocking trying to run 3,000-4,000 sheep to make a reasonable living. In the 1930s the Commissioners began to address the problem by providing 'additionals' (sic), but often well removed from the home blocks.
>
> The 1932 Western Lands Act created a home maintenance area standard ranging from 3500 sheep in the east to 8,500 sheep in the far west (see Condon 2002, p. 171). If that standard had been maintained in the post-war settlement program, we would not have had the continuing need for structural adjustment, dating from the fall in wool prices from about the early 1960s. The position was relieved by the policy change in 1968 (see Condon 2002, p. 270).

Ratcliffe's analysis also shows the wide range of stocking rates used by graziers in the one region. 'The practice has been to stock at the rate of 50–60 sheep to the square mile'. Some graziers stocked at 80 sheep per square mile which 'was considered dangerous'. 'A few carried 40 or so which was universally regarded as

light stocking' (p. 320). He goes on to describe a saltbush paddock in the 1935 drought that had no ephemeral feed left and was stocked at 20–25 sheep per square mile. This rate was regarded as 'safe' by the graziers and as not 'endangering the bush'. This recommendation was supported by C. Goode who indicated that a stocking rate of 20–25 sheep per square mile was required to permit regeneration of the bush (J. McDonald pers. comm.). If the drought continued the grazier expected that the stocking rate would have to be further reduced.

Pick (1942, p. 47) quoted submissions to the 1927 Royal Commission in which Mutooroo, a large holding with a policy of conserving a drought reserve (Anon. 1951), was stocked at 35 per square mile whilst 40 small holdings whose aggregated area was the same as Mutooroo were stocked at 50 sheep per square mile. Donovan (1995) cited a report by C. Goode on a station near Olary running 77 sheep per square mile in 1931 that was devoid of topsoil by 1943. Tynan (2000) noted that stock minima of 100 sheep per square mile were indicated in the 1850s and J. McDonald (pers. comm.) indicated that rates close to or above one hundred sheep per square mile persisted into the 20th Century.

From his experience, Ratcliffe (1970, p. 321) put forward what he regarded as a pessimistic solution to managing climatic variability:

> ...that the fodder reserve of the saltbush can carry, through a prolonged drought, only a fraction of what is regarded as a normal flock, and even of what experience has shown to be a barely economic flock.
>
> The case of the saltbush country gives a fair indication of the reserve-fodder value of the best-balanced pasture to be found in arid Australia. From it one can readily deduce what will take place, during a drought, in country where the evergreen feed is much less abundant. The edible bushes and shrubs will be subjected to gross over-grazing by stock eating anything they can find to keep themselves alive; and the fewer, relatively, the evergreen plants, the more rapidly will they be stripped and the less will be their chance of recovery.

and further (p. 327):

> The inevitably recurring droughts are the weak links in the continuity of prosperous settlement in the Australian inland. In a severe drought, in order to keep themselves alive, the stock have to eat and destroy, often beyond hope of recovery, those long-lived resistant plants on which the stability of the soil itself depends. As far as I can see, only the wholesale evacuation of stock from the threatened country in anticipation of a drought could insure the preservation of the key plants in the vegetation. But even if the accurate forecasting of drought were possible such a policy would neither be practicable nor economic under the conditions that exist in Australia.

Recovery?

As indicated above, despite good rainfall in the early 1930s, recovery was slow to occur. Donovan (1995, p. 83) quotes a finding of the Soil Erosion Committee in 1937 after inspecting a large part of the pastoral region:

> while there is certainly an improvement in the country due to the better season and reduced stocking, there is as yet no permanent regeneration, which must take some years to establish.

With the onset of the 1940s drought it was apparent that pastoral legislation had had 'little real effect' (Donovan 1995, p. 86). The cause was apparent to the Pastoral Inspector C.H. Goode; Donovan (1995, p. 87) quotes the following letter written 12 September 1944:

> [Regeneration] cannot be accomplished except by controlling the controllable causes of denudation and consequent erosion.
>
> After the innumerable inspections which Members of the Board have made during the past 4 years and during the interviews with pastoral lessees or their representatives, generally every other factor has been put forward as the chief cause of this damage to the land, but the fundamental cause – overstocking – generally is discounted, resented and often ridiculed ...

> The efforts of the Board during this period have met with comparatively little success in obtaining the co-operation of pastoral lessees in respect of spelling certain badly affected paddocks and/or limiting the numbers of sheep to numbers which would give their damaged holdings a chance to recover.

Donovan (1995) in his history of the South Australian Pastoral Board describes the legislative progress made in the management of South Australia's rangelands since the degradation episode of the 1920s and 1930s. The raising of a conservation consciousness in the 1960s backed by political power led to the current enforcement of legislation to control stock numbers and prevent further degradation. Fundamental to this process was the legislative commitment to objectively assess individual properties by trained scientific field officers, and to negotiate with property managers the capacity to carry stock based on condition of the land and stocking levels used for the last ten years. R. Tynan (pers. comm.) stated that 'the Pastoral Board decided on this number, not the scientific staff'.

The degradation episode also supported the Board's wisdom of successfully pursuing a policy of encouraging the enlargement of small leases and opposing subdivision of larger leases. 'This has helped to ensure that South Australian rangelands were generally in better condition than those of western New South Wales and Queensland where there was a strong push to break up large holdings' (Donovan 1995, p. 214). The consequences of this latter action will be apparent in later episodes.

The combination of reduced rabbit numbers, favourable rainfall periods of the 1950s and 1970s, enforced legislation on stock numbers and comprehensive monitoring of properties with objective reproducible methods appear to have brought about improvement (e.g. Gibbs 1986). Donovan (1995, p. 212) wrote:

> Although it is difficult to determine precisely when the most severe degradation occurred, there is evidence to suggest that the degradation has been largely arrested and stabilised and in many instances regeneration of vegetation has been encouraged, perhaps not as completely as many conservationists might hope but certainly more than others might fear.

J. McDonald (pers. comm.) indicated that during the program of lease assessment from 1990 to 2000, and more particularly in the period 1995/96 for the North East District, a quick evaluation of long-term change in this District was undertaken. The sites where photos were taken by C. Goode in 1943, and by subsequent Inspectors from 1950 onwards, were located, photographed again, and changes in vegetation, if any, were noted. Substantial change to structural forms and plant composition were noted, effectively summarised as considerable improvement in cover-abundance of perennial species (especially low to medium shrubs) and in land condition.

Evaluations of range condition in the other regions such as Kingoonya Conservation District (north-west of Port Augusta) have also been made on several occasions (Jessup 1951, Lay 1979, Maconochie and Lay 1996, McDonald and Lay 2002). The studies have revealed that vegetation condition based on perennial chenopod shrubs in the District has improved over almost 50 years.

McDonald and Lay (2002) found generally improved rangeland conditions over the last six decades, based on data from 53 photo-points and an additional 45 opportunistic observations. Original photos from the period 1943 to 1967 were compared with the same location during an on-ground visit from 1995 to 1998. While 28 of 53 sites maintained original structural form, many of the remaining sites changed from herbland/annual grassland or bare areas to shrublands.

Tynan (pers. comm.) has provided an assessment of the Gawler rangelands (Tynan 1995). He stated that 16% of the rangeland is still highly disturbed, 32% moderately disturbed and 52% is in acceptable condition. Most of the disturbance relates to distance from water, historical stocking levels and the timing, duration and 'season of use' factors.

A major legacy of the 1920–1939 period was the development of a resource conservation ethic (Donovan 1995). For example, D.G. Wilcox (pers. comm.) indicated that Mutooroo had a policy for many years of selling the whole complement of an age group on the station irrespective of the conditions. This may well have been one of the reasons why it did not suffer as much as neighbouring stations in the drought. This same station was one of the first to attempt to rehabilitate land in South Australia on a very large scale, investing heavily in machines of various kinds and in the labour and seed for reclamation. Furthermore, Holmes and Day (1995, p. 202) found that pastoralists in South Australia have a 'significantly stronger conservation orientation than Australian farmers generally'. They further say that this can be interpreted as recognition of pastoralism's reliance on semi-natural ecosystems.

What do we learn for preventing land and pasture degradation?

1. The history of the episode highlights: (a) how periods of severe drought can amplify damage to grazing enterprises and the resource; and (b) the importance of conservatively managing perennial shrubs to maintain breeding flocks through periods without substantial plant growth.

2. In 1938, Ratcliffe (1970) had come very close to formalising the concept of calculating flexible 'safe' carrying capacity from environmental data. However, it would not be until the 1960s (Episode 6) that Condon (1968) would demonstrate an approach of quantitative analysis using climate data (rainfall) in the calculation procedure. Such an approach is fundamental to addressing the issue of how climate variability affects carrying capacity and to what extent the concept of a 'safe' constant carrying capacity is valid in semi-arid rangelands where extended periods of low rainfall can occur (Tynan 2000).

3. Episode 2 highlighted the need for legislation to protect the resource, but that such legislation would be difficult to enforce because of the uncertainty regarding the causes of degradation (e.g. climate, rabbits, stocking rate). The reason for the success of the South Australian system of resource condition assessment would appear to be its objective, scientific and transparent approach. However, major issues remain in: (a) separating the impacts of climate variability and management; and (b) addressing the communication issue with graziers that 'condition is essentially an ecological concept, whereas management is a production concept' (J. McDonald pers. comm.).

2.4 Episode 3: Gascoyne region of Western Australia in the 1930s

In this episode, we describe the impact of drought and degradation that occurred in the southern rangelands of Western Australia. We concentrate on the general region covered by the Carnarvon Basin, the Gascoyne and Murchison Catchments/Basins and adjacent grazing areas. We refer to this region using the general term 'Gascoyne'. Drought and degradation were extensive throughout the region in the late 1930s (Fyfe 1940). Williams *et al.* (1980) have comprehensively reviewed the unfolding history of degradation in the Gascoyne Basin in Western Australia. The degradation episode was essentially uncovered by a retrospective analysis. However, the drought event throughout the region was sufficiently well recognised at the time for a Royal Commission to be held in 1940 (Fyfe 1940) documenting dramatic stock losses.

Floods in January and February 1961 stimulated an investigation into the condition of the Gascoyne Basin. Subsequent surveys and reports documented degradation of the Gascoyne Basin and resulted in recommendations to reassess property carrying capacity to prevent further 'denudation and erosion' (Wilcox and McKinnon 1972). Reconstruction of time series of animal numbers (mainly sheep) indicated a crash (60–80% reduction) in the mid 1930s with numbers returning after the drought to only 50% of the previous peak that occurred in the early 1930s. Some individual stations lost 80–90% of the flock during the eight-year drought from 1935 to 1942 with devastating financial and human cost (McDonald 1991). Williams *et al.* (1980, p. 26) refer to 'widespread and severe deterioration evidenced between 1920 and 1936', and hence we concentrate on the period from the 1920s to early 1940s. This period included a severe drought, but was preceded by a sequence of above-average rainfall years that allowed stock numbers to build up to levels not seen before or since (Williams *et al.* 1980).

Climate history

Table 2.4 and Plate 2.3 show the 20–year history from 1924/25 to 1943/44 including the extended six–year drought period from 1935/36 to 1940/41. Prior to the first year of extreme drought (1935/36) eight of the nine years had been average to well above-average (e.g. 1932/33). In particular the period 1931/32 to 1933/34 was a sequence of above-average years providing the ideal conditions for stock numbers to build up.

The effect of ENSO on rainfall is not as great in the Gascoyne region as in eastern Australia (Chapter 1). Of the four El Niño years that occurred (1925/26, 1932/33, 1940/41, 1941/42) only one had severe drought (1940/41). The La Niña year of 1938/39 was in the extended drought period and had severe rainfall deficiency (–54%).

Thus the 1930s episode is characterised by a long period (>10 years) of generally favourable conditions followed by six years of well below-average conditions. The search for mechanisms to explain this abrupt change in rainfall in 1935 has as yet been unsuccessful. As briefly reviewed in Chapter 1, recent research (Wright 1997, Telcik and Pattiaratchi 2001) has identified the importance of northwest cloudbands as a source of autumn–spring rainfall for this region. However, no historical reconstruction of northwest cloudbands for the 1930s is available at present.

Some circumstantial indicators of a general climatic 'break-point' at around 1935/36 are:

1. change in numbers of calms at Brisbane observed in January and July and in wind patterns 'particularly in winter (July) from 1933 to 1937 and afterwards' (Chapter 1.2.4, Ward and Russell 1980, p. 89); and
2. the IPO was very *warm* and continued to increase reaching a peak in 1939 (Power *et al.* 1999, Figure 1.3).

Although Perth Mean Sea Level Pressures in the late 1930s were higher than those that had occurred over the previous 10 years, these values do not appear to be anomalous in terms of fluctuations in the long-term record (Nicholls *et al.* 1999).

Williams *et al.* (1980) reviewed some of the climate phenomena affecting rainfall in the Gascoyne Basin and made the following observations (p. 14):

Table 2.4 Extended drought period (brown) during regional degradation Episode 3 in the Gascoyne region. The extended drought period was calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12–month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5). Years in the table are indicated only by the starting year, i.e. 1924 is the period 1 April 1924 to 31 March 1925, referred to in the text as 1924/25.

Episode		Rainfall Anomaly									
Episode 3 Gascoyne WA	Year	**1924**	**1925**	**1926**	**1927**	**1928**	**1929**	**1930**	**1931**	**1932**	**1933**
	% Anomaly	-16	-18	+3	+1	+9	-2	-29	+28	+69	+35
	Year	**1934**	**1935**	**1936**	**1937**	**1938**	**1939**	**1940**	**1941**	**1942**	**1943**
	% Anomaly	+13	-71	-46	-31	-54	-33	-57	+48	+39	-59

> In winter the southern anticyclonic systems reach their northern limit in the Gascoyne area and slightly to the north. These bring rain and high winds to the Basin. However, only intense depressions penetrate the Basin so that winter rainfall also is unreliable.

and with regard to summer rainfall:

> Isohyet maps of the north-west of Western Australia have been prepared by the Australian Bureau of Meteorology for the 51 years from 1909 to 1959 in which there were [summer] cyclonic depressions. Significant rain was brought to various parts of the Basin by forty-two of these cyclonic events. Some years had no such depressions, one had three and ten [had] two. Only five of these forty-two depressions brought rain (25 to 50 mm on average) to all the Basin, and there was a tendency for the centre and east of the Basin to have more depressions and heavier rainfall than the western end.

Cyclones in north-western Australia and northern Australia are more likely to occur under La Niña conditions (N. Nicholls pers. comm.). The year 1938/39 was the only La Niña year between 1925/26 and 1946/47, thus reducing the likelihood of drought-breaking rainfall in summer in the region from cyclone occurrence.

Data sources and chronology

Time series of animal numbers are available from 1934 for an anonymous station 'E', and for the whole Catchment as reported in Wilcox and McKinnon (1972). Numbers back to 1925 are reported in Williams *et al.* (1980) and Payne *et al.* (1987) for the adjacent Carnarvon Basin. Animal numbers back to 1900 have been reconstructed using government livestock statistics. For simulations of pasture growth, a 'herbage' parameter set was derived from the Boolathana grazing trial (Watson *et al.* 1997a), which is in the Carnarvon Basin, immediately to the west of the Gascoyne Catchment. The yearly period from April to March was used to best align rainfall, growth and stock numbers (Figure 2.3).

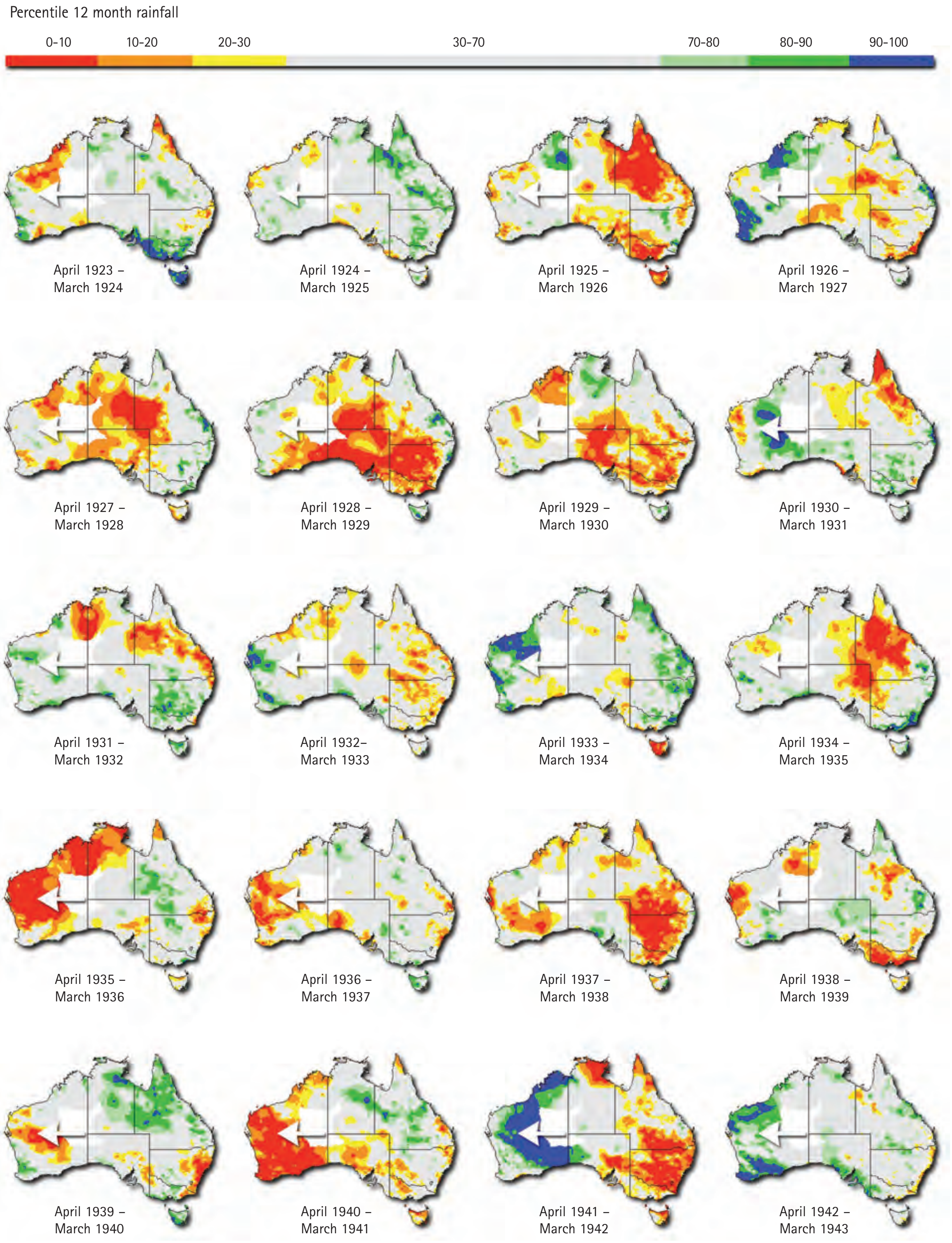
The generally favourable period (1915 to 1934) included individual years with low or average rainfall (Figure 1.1h, Plate 2.3) and especially low growth of 'herbage' species (e.g. Figure 2.3). During these periods substantial pressure would have been placed on perennial species. There were only small reductions in animal numbers in the 1920s droughts and hence high grazing pressure was likely to have occurred (e.g. 1929). Williams *et al.* (1980, p. 26) refer to 'widespread and severe deterioration evidenced between 1920 and 1936'. They also indicated that there was only one pastoral inspector for the whole of Western Australia at the time, reducing the likelihood of comprehensive assessment.

The two rainfall stations, representing the Murchison and west Gascoyne, in 1934/35 had 50–70% of the average pasture growth for the previous nine years, with only a small reduction in sheep numbers. The next two–year period, from April 1935 to March 1937, had very low rainfall and virtually nil 'herbage' growth at some stations. Hence almost all the grazing pressure would have been on perennial vegetation such as chenopod shrubs and browse. McDonald (1991) reports several examples of feeding stock by cutting scrub. Similar periods of negligible pasture growth occurred in 1938/39 to 1939/40 and animal numbers declined to very low levels. In the case of property 'E' and the Murchison region, stock numbers in 1936 were 20–40% of the previous favourable period of the early 1930s, whilst the Gascoyne Catchment numbers were down to 50% in 1936 and to 30% in 1937 (Wilcox and McKinnon 1972).

Observations and analysis

McDonald (1991, p. 219) compiled a history of 33 properties in the Gascoyne concentrating on the human stories and ownership changes. She highlighted the severity of the drought, especially its length and the call for government action resulting in a Royal Commission into the economic and financial position of the industry.

Episode 3
Gascoyne – Western Australia 1924-1943



April 1923 – March 1924

April 1924 – March 1925

April 1925 – March 1926

April 1926 – March 1927

April 1927 – March 1928

April 1928 – March 1929

April 1929 – March 1930

April 1930 – March 1931

April 1931 – March 1932

April 1932– March 1933

April 1933 – March 1934

April 1934 – March 1935

April 1935 – March 1936

April 1936 – March 1937

April 1937 – March 1938

April 1938 – March 1939

April 1939 – March 1940

April 1940 – March 1941

April 1941 – March 1942

April 1942 – March 1943

Plate 2.3 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 3. The El Niño years were 1923/24, 1925/26, 1932/33, 1940/41, 1941/42. The La Niña years were 1924/25, 1938/39.

Episode 3 – Gascoyne region of Western Australia 1930s

Time period: 1924 to 1943
Base period: 1926 to 1934

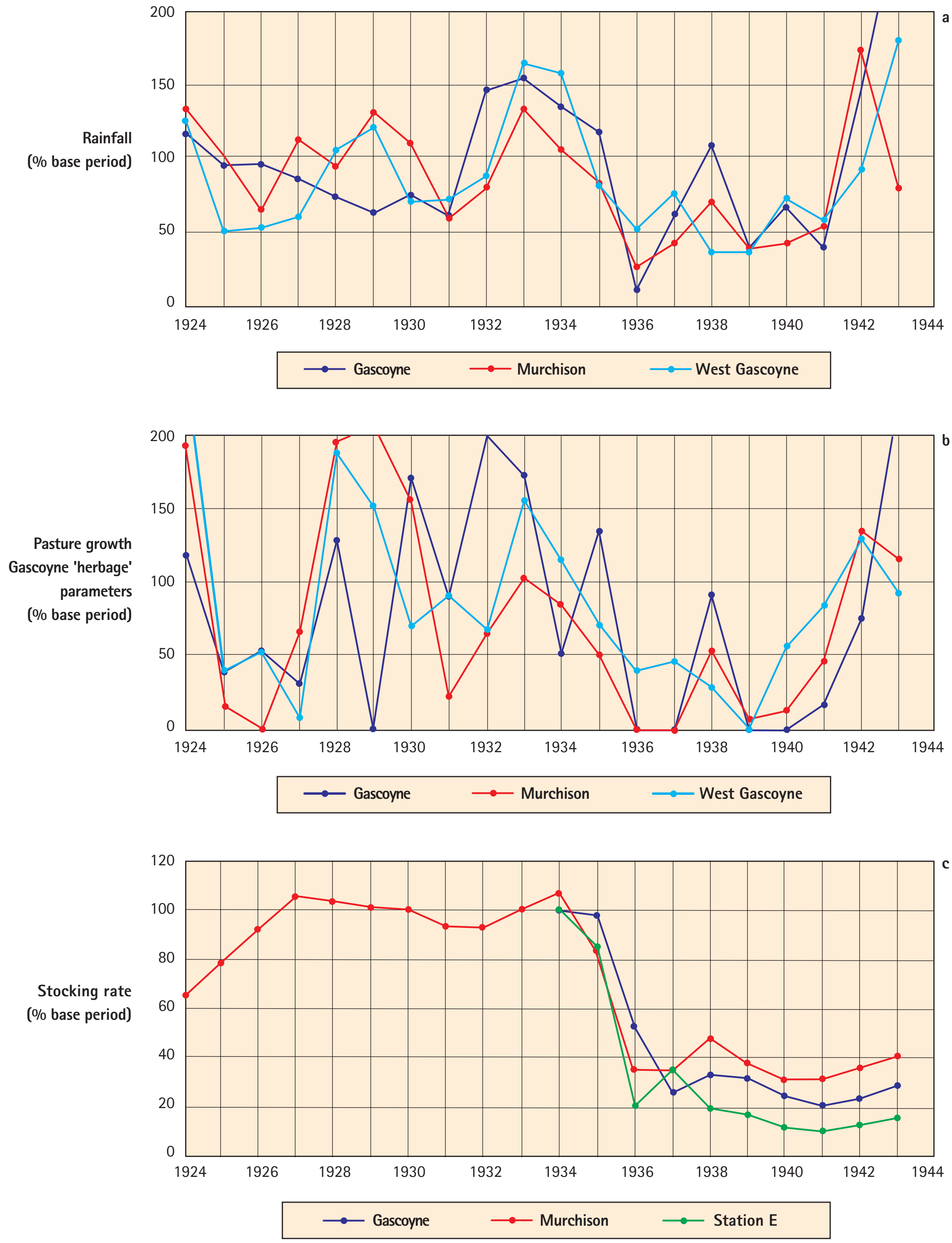


Figure 2.3 Episode 3 for Western Australia in the 1930s. Time series of: (a) rainfall; (b) simulated pasture growth using Gascoyne 'herbage' parameter set (Boolathana grazing study); and (c) reported stock numbers. Rainfall stations used were Bureau of Meteorology (BoM) Station 06000 to represent the Gascoyne Catchment, BoM Station 06003 representing west Gascoyne and BoM Station 06069 representing the Murchison Catchment. The annual period is 1 April to 31 March. Data have been plotted with the X-axis being the 'year' at the end of the 12–month period. Data are expressed as a percentage of the mean for the base period 1925/26 to 1933/34. The year 1935/36 has been taken as the first year of the consecutive drought/degradation sequence.

McDonald (1991, p. 219) further observed:

> The drought dragged on for seven long years and before the devastation was over, it took its toll of man as well as beast. Looking over the history of the stations it will be noted a number of the original pioneers passed away during that time, even though many were not old men at the time.

Williams *et al.* (1980) refer to *Pastoral Reports* and maps of property inspections made in 1920 that describe the different vegetation communities as being in good condition. The descriptions contrast to those made in 1969/70 that refer directly to the absence of these communities and the loss of surface soil.

In 1940 a Royal Commission was held into the 'financial and economic position of the pastoral industry in the leasehold areas of Western Australia' (Fyfe 1940). While the task of the Royal Commission was to consider the problems of the industry in general, many arising because of the impact of the Great Depression, the drought of the late 1930s precipitated the call for the Royal Commission. Some comments on the Royal Commission have been provided by I. Watson (Appendix 1 in McKeon and Hall 2002).

> The Terms of Reference of the Royal Commission did not specifically include resource degradation, either as a factor in the economic and financial position of the industry or as a land management issue influenced by pastoral activities.
>
> Drought alone was seen as the major biophysical issue facing the pastoral industry, rather than drought and resource degradation. The emphasis was clearly on measures to keep stock alive and on enabling restocking, rather than protecting the resource. Fyfe recommended government (including Commonwealth) assistance for restocking following the drought.
>
> Few experts on *'vegetation and pastures'* gave evidence to the Commission.

House *et al.* (1991, p. 31) summarised the findings as follows:

> The 1940 Royal Commission recognised that south of Kimberley, plummeting prices for wool in the 30's together with the high sheep numbers of 1934 and the length and severity of the drought period experienced from 1935 to 1942 spelled financial and environmental disaster. Sheep numbers fell from 5.5m [million] in 1934, to 3.05m [million] in 1939. Cattle numbers also suffered comparable losses. The damage to the vegetation was equally disastrous and a matter of great concern to pastoralists at the time. In the Murchison–Meekatharra area, it was estimated that by 1940, 75% of the highly productive perennial Saltbush shrubs and 25% of the Acacias had been destroyed. Losses of up to 90% of scrub and shrubs were reported. The 1940 Royal Commission recognised that overstocking, inadequate lease development, and lack of drought management and poor financial management by pastoralists contributed to the financial collapse of the pastoral industry in the late 1930's and the extensive range deterioration.

Wilcox and McKinnon (1972, p. 4.1) made the following comment on the Royal Commission:

> Although Fyfe (1940) had the impression (*sic.*) that in only a few localities had soil erosion permanently reduced the carrying capacity over extensive areas, he did report on the shifting of the surface soil on many stations, the increase in the size of scalds and the ridges of sand created by wind. These would be signs of erosion which were current but which could be remedied by the application of proper grazing practices. Fyfe also reported that overstocking was common in the pastoral areas with consequent heavy damage and stock losses.

However, subsequent stock numbers returned to only 50–70% of the peak numbers of the early 1930s and had large year-to-year fluctuations in response to annual variation in rainfall (Wilcox and McKinnon 1972, p. 4.3): 'These great fluctuations in stock numbers show that the catchment rangelands are being exploited for maximum production since variations in rainfall have an immediate effect on stock carried'. Further, they cite examples where the estimated carrying capacities of six stations in 1965 had been reduced to approximately half of estimates in 1920.

Jennings *et al.* (1979, p. 34) stated in an assessment of pasture productivity for Western Australia:

> Pastoral leases in Western Australia have been assessed at intervals since the 1920s for their capacity to carry grazing animals. Until 1969 estimates of carrying capacity for rental purposes were based upon the condition of the country at the time of inspection and were tempered and varied according to the experience and ability of the appraiser to divine the long-term carrying capacity of the land. It is only since 1969 that pastoral lands have been classified according to their potential (original) carrying capacity.
>
> In the short-time which has elapsed since pastoral settlement, marked changes in carrying capacities made on the basis of the then present condition have occurred.

and later:

> The capacity of the land to support stock was shown to be about one-third of that originally estimated. Reductions in estimated carrying capacities have been a regular feature of most appraisements by the Department of Lands and Surveys made on stations since the 1920's.
>
> These necessary reductions are considered to be the result of the ignorance of both occupiers and Government in estimating the capacity of the land to sustain its productivity. These alterations to present carrying capacity have also been associated with a reduction in the condition of the pastures.

The major aspects of erosion of the Gascoyne Catchment were not fully documented until the 1960s (Wilcox and McKinnon 1972). Their survey was in response to flooding that occurred in Carnarvon in February 1961. The severity of the flooding was attributed to degradation of the Catchment (Lightfoot 1961 cited by Wilcox and McKinnon 1972).

Williams *et al.* (1980, p. 5) summarised Wilcox and McKinnon's findings thus:

> The eroded areas were those which had soils susceptible to erosion and were capable of supporting palatable and durable pastures. They received frequent run-on water from areas upslope, were readily accessible to sheep and maintained high levels of animal production. Their preferential use, when combined with systems of heavy continuous grazing, has produced the devastated areas.

Recovery?

Wilcox and McKinnon (1972) recommended a reduction of approximately 40% in stock numbers from 416,833 to 237,290 sheep units, and that 'continuous use of many rangelands should be avoided, particularly after severe droughts and in degraded and incipiently eroding pastures' (Williams *et al.* 1980, p. 1.1). D. Wilcox stated 'these recommendations were violently opposed by the pastoral lessees who persuaded Government that a review of the original recommendations should be carried out. Accordingly, another more brief inspection of the Catchment was made by two other departmental officers. This inspection recommended that the safe carrying capacity would be about 330,000 sheep units'. This figure was acceptable to most lessees, with government then moving to reach paddock destocking and stock reduction agreements on most properties (Morrissey 1984). With the occurrence of drought (1979/80) and low wool prices, the implementation of 'closely supervised-grazing' lapsed (D. Wilcox pers. comm.).

The effect of the 1970s drought on the capacity of graziers to carry stock has been used as a measure of resource condition (Jennings *et al.* 1979, p. 39).

> The drought in the pastoral areas in the period 1970 to 1977 reduced total sheep numbers south of Kimberley by proportionally as many as did the severe drought of 1936 even though the stock numbers at the beginning of the 1970 drought were lower. The carrying capacity of the vegetation or pastures must therefore be presumed to be lower today than it was 40 years ago. More importantly, if present stocking policies continue, the capacity of the country to support stock in successive droughts will be reduced as each drought takes its effect.

House *et al.* (1991, p. 37) in a report of the Western Australia parliamentary Select Committee on Land Conservation commented on the interaction of drought and resource management. They provided the following conclusion for the Carnarvon Basin which is in the western part of the Gascoyne region discussed here. The comments below from House *et al.* follow from the release of the Carnarvon Basin survey report (Payne *et al.* 1987), part of an ongoing series of reports starting with that of Wilcox and McKinnon (1972):

> An assessment was undertaken for this Discussion Paper of the effect of recent grazing pressures in the Carnarvon Basin on the capability of leases to maintain adequate stock numbers during the 1980 drought. The Carnarvon Basin was chosen as it is the only Regional Survey area for which information is provided for each lease on their carrying capacity under present condition (i.e., the Recommended Carrying Capacity, which assumes that leases are fully developed); the annual average stock numbers run (generally averaged over the period from the late sixties or early seventies to the mid eighties); the lowest number of stock run during this period, which mostly coincided with the 1980 drought; and an assessment of the adequacy of the watering points.
>
> A reduction during the drought of 50% or more of the annual average number of stock on each lease was arbitrarily chosen as representing an economically unacceptable consequence of the drought. On this basis, 32 of the 54 leases in the Carnarvon Basin suffered significant reductions of stocks during the drought. In fact the average number of stock on these leases during the drought was found to be 3 273 compared to the annual average figure of 10 850, or a reduction of 69.8%.
>
> The extent to which each lease was overstocked was determined by comparing the Recommended Carrying Capacity calculated by the Department of Agriculture with the annual average stocking rate. A lease was considered to be overstocked if the latter was more than 10% in excess of the former. On this basis, of the 32 leases suffering severe stock reductions during the drought, 20 had been overstocked over the period recorded. Inadequate, or lack of, watering points creating local problems of overstocking, occur on at least 35 of the 54 leases in the Carnarvon Survey area [16, citation not available]. Of the 32 leases suffering severe stock reductions during the drought, 27 were considered by the Department of Agriculture to be inadequately watered. Overstocking due to inadequate lease development was therefore a major cause of the stock losses during the drought.
>
> Of the 32 leases suffering severe stock reductions during the drought, 50% (16 leases) were both inadequately developed and had maintained excessive stock levels over the 10-15 year period before and after the 1980 drought. However the stock reduction which occurred during the drought could also be partly explained by pastoralists deliberately removing stock to prevent excessive range deterioration. Whether the reduction in stock numbers occurred as a result of sheep dying on stations or being removed from stations cannot be determined. The important factor is that previous overstocking severely reduced the carrying capacity of leases during the drought.
>
> The results of this analysis indicates that many pastoralists in the Carnarvon Basin have not adopted management practices which operate within the constraints imposed by drought.

The rapid decline in sheep numbers in 1936 and 1937 quite clearly occurred as 'losses' i.e. deaths, on stations or stockroutes. Questionnaires completed by individual pastoralists for the Fyfe Royal Commission show the extent of these losses and the 'deficiency of natural increase' resulting from the loss of breeding stock. Quoting 34 stations in the Gascoyne, Fyfe (1940, Section 506) showed that sheep numbers in 1934 were 778,434. Losses over the period 1935 to 1939 were 669,085, with a further 'deficiency of natural increase of 429,340' presumably due to lost lambing opportunities.

While the drought was obviously a major cause of such rapid and horrendous decline, Williams *et al.* (1980) considered that stock numbers were excessive going into the drought and that the drought merely advanced the inevitable collapse by a year or two. The system was 'already well on the way to collapse' (Williams *et al.* 1980, p. 24).

Several aspects of the 1930s episode highlight its importance in accelerating degradation:

1. high grazing pressure combined with the severity of the drought as evidenced by the low rainfall, the lack of 'herbage' growth in several years, and the collapse of stock numbers;
2. observations of loss of perennial plants made to the 1940 Royal Commission;
3. failure of stock numbers to return to those of the early 1930s;
4. the apparent erosion and lack of cover on the Catchment as shown by floods of 1961; and
5. the apparent inability of the resource to support stock numbers in subsequent droughts (1979/80).

The last word

Severe drought is inevitable in this environment, likely to occur at least once, and possibly twice, within the working life time of each property manager. Neither sophisticated seasonal forecasting nor 100 years of records are needed to make this observation. Nor is this knowledge limited to scientists, as the following quote from Royal Commissioner Fyfe (Fyfe 1940, Section 158) shows:

> To forecast the future with any degree of certainty is, of course, impossible, but if it can to some extent be measured from a seasonal point of view in terms of the past, it appears that one investing money in the industry in these areas would be wise to allow for the probability of a severe drought lasting several years having to be encountered about every fifteen years to twenty years, the seasons between fluctuating from very dry to very good, with occasional series of successive good seasons.

What do we learn for preventing land and pasture degradation?

1. The climatic forcings that may have contributed to the long (six–year) drought in Episode 3 are not yet understood and hence the capability to provide forecasts or warnings of its re-occurrence is limited. However, the fact that such a severe six–year period of drought (1935/36 to 1940/41) has occurred in the historical record is, in itself, a warning for current resource managers (Chapter 3).
2. The rapidity with which animal numbers declined indicates the sensitivity of some grazing systems to severe drought, especially those in which degradation has already occurred.
3. When seasonal conditions and economic forces combine to encourage the build-up of stock numbers to excessive levels, a crash is an inevitable consequence.

2.5 Episode 4: Western New South Wales in the 1940s

Following good rains in western New South Wales and South Australia during 1939, severe drought conditions developed from 1940 to 1945. Because of World War II, reporting of the drought was restricted (Klepac 1996, p. 79). In December 1944 *The Sydney Morning Herald* commissioned a journalist (K. Newman, 1944a, 1944b, 1944c, 1944d, 1944e), a photographer (J. Leonard) and an artist (R. Drysdale), to describe what was occurring in western New South Wales (Plate 2.4). Newman's reports raised the awareness of public and government and coincided with a government initiative for the conservation of the State's natural resources. Stock losses, especially in 1944, were high with 60–80% reductions in western Pastures Protection Districts (PPDs). Annual 'dust storm days' around Australia exceeded 100 for 1944 and 1945 (McTainsh and Leys 1993) with high frequencies observed at Charleville and Wagga Wagga (Figure 1.8, Chapter 1).

Climate history

Table 2.5 and Plate 2.5 show the 20–year period from 1930/31 to 1949/50 including the extended drought period from 1941/42 to 1944/45. Prior to the extended drought period there was high year-to-year variability

Table 2.5 Extended drought period (brown) during regional degradation Episode 4 in western New South Wales. The extended drought period was calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12-month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5). Years in the table are indicated only by the starting year, i.e. 1930 is the period 1 April 1930 to 31 March 1931, referred to in the text as 1930/31.

Episode	Rainfall Anomaly										
Episode 4 Western NSW	Year	**1930**	**1931**	**1932**	**1933**	**1934**	**1935**	**1936**	**1937**	**1938**	**1939**
	% Anomaly	+12	+29	-34	+4	-26	+4	+8	-61	+1	-7
	Year	**1940**	**1941**	**1942**	**1943**	**1944**	**1945**	**1946**	**1947**	**1948**	**1949**
	% Anomaly	-11	-48	-5	-42	-55	+3	-6	-1	+20	+40

with severe drought years (1932/33, 1934/35, 1937/38) interspersed by average or above-average years. Some regions of western New South Wales had extremely abundant vegetation growth during 1939 (Ker Conway 1989). The following year (1940/41) was an El Niño year. January–December 1940 had the lowest rainfall on record in many locations (Pickard 1993), but was followed by substantial rainfall in January 1941. Hence, although the calendar year 1940 is regarded as an extreme drought year, the period 1 April 1940 to 31 March 1941 is not indicated as a major anomaly in Table 2.5. The carryover pasture from 1939 provided animal feed (Beadle 1948) and likely protection from wind erosion (McTainsh and Leys 1993). The El Niño year of 1941/42 initiated the extended drought period including two extreme back-to-back years (1943/44 and 1944/45). Average rainfall (1945/46, 1946/47, 1947/48) and well above-average rainfall in the late 1940s resulted in some recovery and allowed restocking (Ker Conway 1989).

During the 20-year period the two La Niña years (1938/39, 1947/48) had average rainfall. Three of the four El Niño years (1932/33, 1940/41, 1941/42) had below-average or severe rainfall deficiency.

The IPO 'index' was *warm* from 1922 until 1945. Both the IPO and PDO 'indices' changed phase (i.e. from *warm* to *cool*) around 1945. Mantua and Hare (2002) identified the periods 1925–1946 and 1947–1976 as different 'PDO regimes'.

Thus the 1940s episode is characterised by yearly fluctuations of wet and dry conditions for 10 years up to 1940, followed by a drought sequence for five years including successive extreme drought years (1943/44, 1944/45). A return to average or above-average conditions (1945/46 to 1949/50) was associated with a major change in phase of the IPO/PDO.

Data sources and chronology

Animal numbers used were those reported for each Pastures Protection District in New South Wales at 31 December each year. The stock numbers were combined with Beadle's (1948) time-series by establishing regression relationships for the period of overlapping data.

Two sets of pasture parameters ('perennial grass' and 'herbage') were used. The period January to December was used for each time-series to align climate and animal numbers (Figure 2.4).

Unlike previous episodes there is no clear break-point between a period of several years of high rainfall followed by lower rainfall. The episode overlaps to some extent with the end of Episode 2. The period 1931 to 1934 appears to have had reasonable rainfall but simulated pasture growth suggests severe feed deficiencies at some locations in 1933 and 1934. The year 1935 had generally low rainfall and growth, and the associated a

Russell Drysdale (born Great Britain 1912, arrived Australia 1923, died 1981)
Sunday Evening, (1941). Oil on asbestos cement sheet, 60 x 76 cm.
Art Gallery of New South Wales ©AGNSW. Photograph: Jenni Carter for AGNSW [acc# 7217]

b

Russell Drysdale (born Great Britain 1912, arrived Australia 1923, died 1981)
Moody's Pub, (1941). Oil on plywood, 50.9 x 61.4 cm. Purchased 1942 National Gallery of Victoria, Melbourne
Photograph: Supplied by National Gallery of Victoria, Melbourne ©Reproduced with permission of the artist's family

c

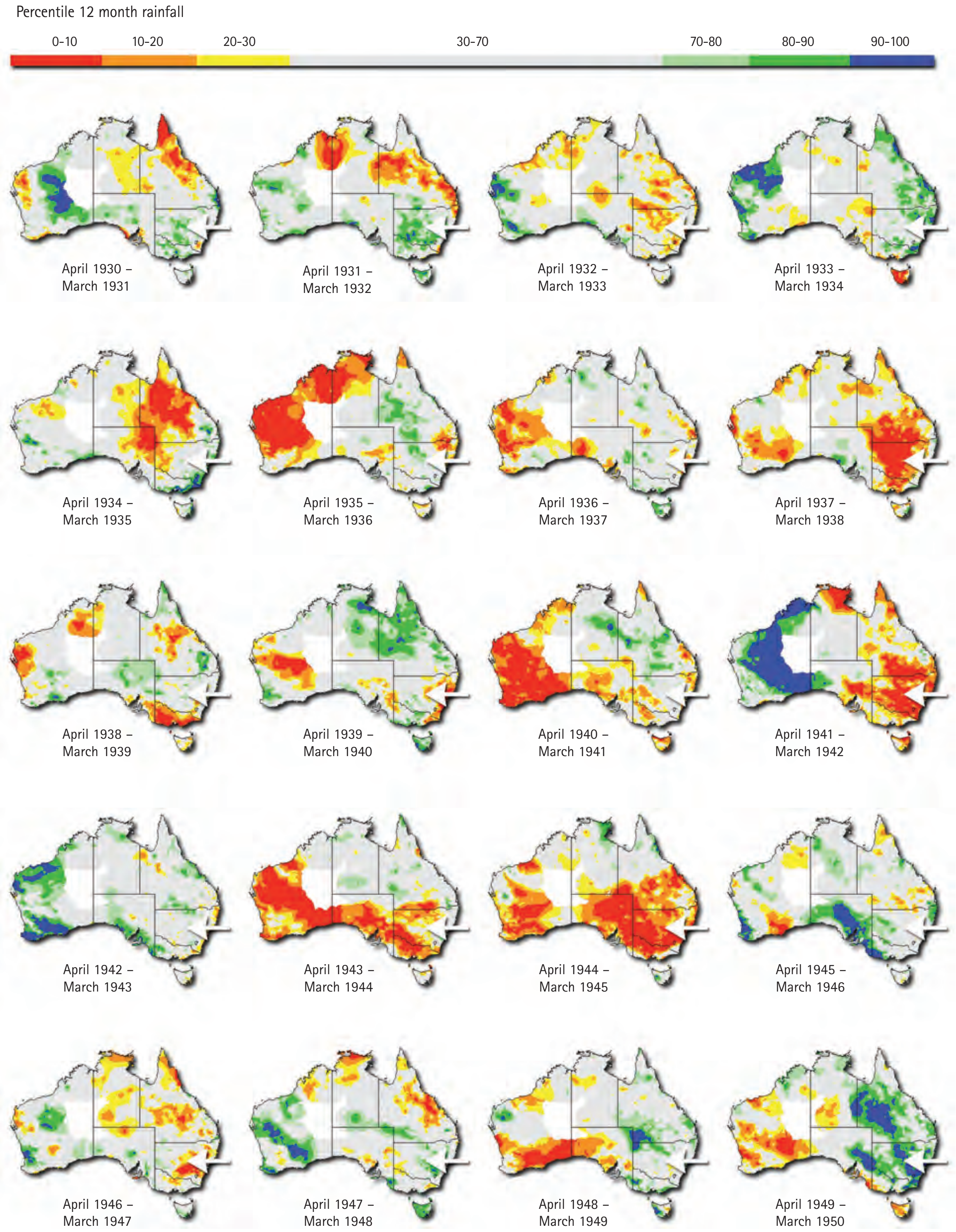
Russell Drysdale (born Great Britain 1912, arrived Australia 1923, died 1981)
Walls of China, (1945). Oil on hardboard, 76.2 x 101.6 cm.
Art Gallery of New South Wales ©AGNSW. Photograph: Christopher Snee for AGNSW [acc# 7631]

d

Russell Drysdale (born Great Britain 1912, arrived Australia 1923, died 1981)
Crucifixion, (1946). Oil on plywood, 76 x 101.6 cm.
Gift in memory of Hugh Alexander McClure Smith CVO by his wife and daughter 1963 Art Gallery of New South Wales
Photograph: Brenton McGeachie for AGNSW [acc# OA1.1963] ©Reproduced with permission of the artist's family

Plate 2.4 A selection of works by artist, Sir Russell Drysdale (1912–1981), painted during the period of Episode 4 in western New South Wales. The development of the drought and increasing degradation is captured in the these paintings from its beginning in 1941 (Plate 2.4 (a) and (b)) to 1945 (Plate 2.4 (c) and (d)). Russell Drysdale travelled through western New South Wales with *The Sydney Morning Herald* reporter, K. Newman, and photographer, J. Leonard, in December 1944.

Episode 4
Western New South Wales 1931-1950



April 1930 – March 1931
April 1931 – March 1932
April 1932 – March 1933
April 1933 – March 1934
April 1934 – March 1935
April 1935 – March 1936
April 1936 – March 1937
April 1937 – March 1938
April 1938 – March 1939
April 1939 – March 1940
April 1940 – March 1941
April 1941 – March 1942
April 1942 – March 1943
April 1943 – March 1944
April 1944 – March 1945
April 1945 – March 1946
April 1946 – March 1947
April 1947 – March 1948
April 1948 – March 1949
April 1949 – March 1950

Plate 2.5 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 4. The El Niño years were 1932/33, 1940/41, 1941/42, 1946/47. The La Niña years were 1938/39, 1947/48.

Episode 4 – Western New South Wales 1940s

Time period: 1931 to 1950
Base period: 1931 to 1940

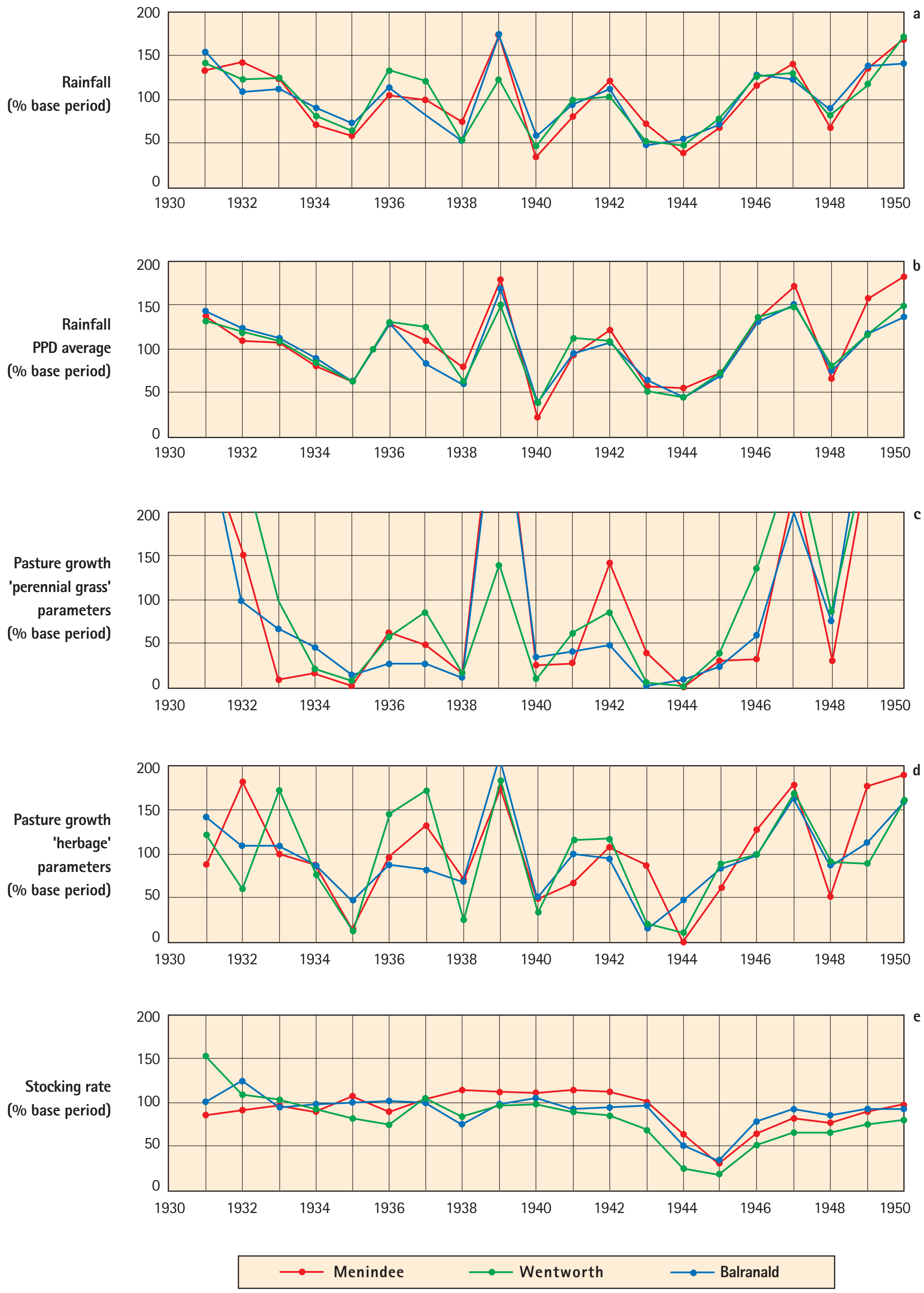


Figure 2.4 Episode 4 for western New South Wales in the 1940s. Time series of: (a) rainfall (station); (b) rainfall Pastures Protection District (PPD spatial averages); (c) simulated pasture growth using 'perennial grass' parameter set; (d) simulated pasture growth using Kinchega 'herbage' parameter set; and (e) reported stock numbers. The annual period is 1 January to 31 December. Data are expressed as a percentage of the mean for the base period 1931 to 1940. The year 1943 has been taken as the first year of the consecutive drought/degradation sequence.

dust storms prompted the surveys of soil erosion in eastern South Australia described by Ratcliffe (1970) in Episode 2. Subsequent years (1936–1938) had suitable conditions for pasture growth ('herbage' parameter set), despite low annual rainfall. However, the simulation of plant growth with dynamic grass basal area suggests that a delayed recovery of pasture productivity occurred during this period. Pickard (1990, p. 246) refers to 'rabbit plagues' during the mid 1930s. In an autobiographical account a grazier, R. Rees (pers. comm.), referred to several years in the 1930s as 'rabbit droughts', especially 1934. These 'plagues' were likely to have reduced the value of the good years.

The year 1939 had very high rainfall and produced a spectacular growth of vegetation (Ker Conway 1989). Ker Conway (1989) recorded that her father bought a fresh herd of cattle to reduce the fire hazard. In contrast to 1939, the year 1940 was exceptionally dry. The years 1941 and 1942 appear to have reasonable rainfall and potential pasture growth ('herbage' parameter set). However, the 'perennial grass' pasture growth simulation suggests reduced growth due to carryover effects of the 1940 drought on grass basal cover. The years 1943 to 1945 had 50–60% of rainfall of the previous base period with years of negligible pasture growth. Stock numbers reported for 1945 were 20–30% of the 1930s decade (Figure 2.4).

Observations and analysis

Jill Ker Conway's autobiography 'Road from Coorain' (1989) described her experiences as a young girl helping her parents during the drought. The 'embryo' of the drought began in the very dry year 1940. As indicated above, the year before (1939) produced a large quantity of pasture growth and graziers retained stock or even stocked up to use the feed and reduce risk of bush fires (Ker Conway 1989). Beadle (1948, p. 91), analysing year-to-year variation in livestock numbers drew attention to this paradox:

> 1938, a dry year, was followed by a very good season in 1939; there was only a slight increase in the number of sheep. In 1940, one of the driest years in the history of the west was experienced; the Milparinka rainfall for this year is the lowest ever recorded for any station in New South Wales. However, there was actually an increase in the number of sheep during that year. Such increases can usually be attributed to the fact that in one good season a vast amount of herbage is produced, far in excess of the annual requirements of the sheep for that year. The herbage dries and is enough to feed the sheep during the following year, which is usually dry. If rain falls during the middle of the dry year a little green feed is produced, sufficient (in the case of autumn lambing) to save the ewes and the lambs after weaning. Consequently, the total number of stock may increase during a dry season.

Ker Conway (1989, p. 53) described from her first-hand experience the unfolding of the drought:

> In 1941, the only rain of the year was a damp cold rain with high wind which came during the lambing season in May and June and carried off many ewes and their newborn lambs. After that there were no significant rainfalls for five years. The unfolding of a drought of these dimensions has a slow and inexorable quality. The weather perpetually holds out hope. Storm clouds gather. Thunder rolls by. But nothing happens. Each year as the season for rain approaches, people begin to look hopefully up at the sky. It mocks them with a few showers, barely enough to lay the dust. That is all.

By 1944 dust storms were occurring every two to three weeks. Sheep were starving and dying and graziers had insufficient numbers to warrant shearing. 'Now so much of our land was without vegetation that the slightest breeze set the soil blowing' (Ker Conway 1989, p. 70). There was a shortage of rain in the critical months from June to September and conditions were comparable with those of 1914 – the worst on record. There was no feed in north-eastern South Australia (Foley 1957, p. 168). The South Australian Pastoral Board noted 'The 1944/45 Season, having followed two previous very dry years, can be written down as the driest and worst season on record in pastoral areas' (Donovan 1995, p. 92). Stock losses of up to 75% were common with some flocks being completely wiped out (Donovan 1995).

The drought in 1944 was widespread throughout New South Wales and parts of South Australia. Foley (1957, p. 76) noted for New South Wales:

> In February 1944 the 'position in the Riverina and adjacent pastoral divisions of New South Wales and Victoria' were 'still extremely bad'. In May 'the worst drought in the outback for 25 years' was killing thousands of sheep and cattle. The far west, north-west and south-west were the most seriously affected. In the Broken Hill district 20 per cent of the district's 600,000 sheep had died as the result of a cold snap. There was no feed within 100 miles of the town. Heavy losses were reported from Goodooga. It was 'the worst drought in 42 years in northern and western parts of New South Wales'. Thousands of sheep were dying. There were appeals for the release of men from the army for scrub cutting in New South Wales and Queensland.
>
> The Minster for Agriculture estimated the current drought losses throughout Australia at £20 million. Ninety per cent of New South Wales was suffering. Some rain fell in May but in July drought conditions continued in many parts of New South Wales 'from the Riverina to the Far North-West' with serious loss of stock. It was reported that nearly 150,000 sheep died in the Bourke district in the worst drought for 40 years.
>
> In August 1944 'losses of 50 per cent of flocks' were 'common in the Western Division of New South Wales'. 'In the western Riverina flocks were reduced by as much as 70 per cent'. There was still much hand feeding of stock. In September the drought in southern and south-western New South Wales was said to be the worst in the State's history. Hand feeding and water carting were being carried out in 'conditions worse than 1864 or 1902 or 1914'.
>
> It was stated in October that more than one million sheep had died in the New South Wales drought area which extended to the borders of South Australia and Queensland. The Riverina and South-West 'were gripped by the severest drought on record – worse still it was a Spring drought'.
>
> In November there was a shortage of meat, milk, eggs and poultry 'all the land south of a line from Bourke to Orange was desolate and devastated'. 'Between Wentworth and Broken Hill the last good rain was in October 1942. Nearly 300,000 head of stock have perished already in the Wentworth district alone.'
>
> Frequent and intense dust storms were experienced towards the end of the year. 'The like had never previously been experienced in New South Wales.'

And later (p.168):

> Erosion was serious in many parts of South Australia, particularly in the Murray and northern districts where the top soil was being stripped in almost any wind. Dust storms prevailed in the north-west and north-east in January 1945.

At Coorain in May 1945 'the last sheep began to die by the hundreds' and 'no amount of digging could prevent the silting-up of fences' (Ker Conway 1989 p. 76-77). Dust storms prevailed in the north-east and north-west of South Australia in January (Foley 1957). The drought continued in parts of New South Wales through 1946 with drought-breaking rains at Coorain in 1947.

The impact of drought was great even on stations with a good drought reserve management policy such as Mutooroo (Anon. 1951, p. 49):

> Drought conditions of varying degrees of severity occurred in 1938, 1940, 1944, 1945 and 1948, the 1944/45 drought being the longest in duration in the history of the Company. From April, 1943, to June, 1945, there was no general rain; severe sandstorms played havoc with the unsheltered plains, blowing away or smothering most of the feed. The 1945 shearing disclosed the loss of 24% of the sheep, and the percentage would have been much greater but for water carting and scrub cutting.
>
> About 30 men were employed to pull scrub for the last 12 months of the drought, and more than a million gallons of water were carted by 3-ton lorries with trailers to paddocks where the bush and pulled scrub lasted long enough to keep the sheep alive.

> There was no possibility in 1944 of moving the flocks over the bare plains into the main shearing shed, and arrangements had to be made to shear in the paddocks, with portable plants. The organisation of this was difficult, but eventually it worked out quite satisfactorily – so well, in fact, that after the drought broke, it was decided to shear in paddocks the following year, in order to give the young seedlings on the plains and around the shearing shed a chance to become well established.

Dust storms and wind erosion

This episode is characterised by the extensive and frequent dust storms that occurred.

Beadle (1948, p. 68) wrote:

> There is little doubt that the intensity and the frequency of dust-storms are increasing. This is due not only to the fact that the 1944-45 drought is the worst on record (for certain parts of Australia, at least) but also to the ever-decreasing area of country permanently protected by perennial vegetation.

McTainsh and Leys (1993, p. 193) in a review of wind erosion drew attention to:

> A map of soil erosion by MacDonald Holmes (1946), compiled from a number of sources, provides an overview of the extent of soil erosion, and in particular wind erosion, up to the early 1940s. Most of the grazing lands of western New South Wales, extending into South Australia, plus the cultivated land in the Victorian Mallee and the Eyre Peninsula, are described as serious wind erosion areas.

Ker Conway (1989, p. 59) also provided first-hand account of the conditions:

> A dust storm usually lasts days, blotting out the sun, launching banshee winds day and night. It is dangerous to stray far from shelter, because the sand and grit lodge in one's eyes, and a visibility often reduced to a few feet can make one completely disoriented. Animals which become exhausted and lie down are often sanded over and smothered. There is nothing anyone can do but stay inside, waiting for the calm after the storm.

Ker Conway (1989, p. 54) records that 'by 1942, it was apparent that the drought could be serious and their [her parents] levels of anxiety began to climb'. She records (p. 58) the 'first terrible dust storm arrived boiling out of the central Australian desert' in March 1943. McTainsh and Leys (1993) calculated the number of dust storm days for 28 stations around Australia for 1942 to 1985. Dust storm days rose from 50 in 1942, to 60 in 1943 and then peaked at about 120 in 1944 and 100 in 1945. R.W. Condon (pers. comm.) cites the diary of Withers (1989) reporting 19 November 1944 as the 'worst dust-storm in Australia's history' and 'the storm blew across the Tasman and tinged the snow on the mountain peaks of New Zealand with the red of Australia's heartland'.

First-hand accounts (Beadle 1948, Ker Conway 1989, Condon 2002) describe devastation of these storms on land, pasture, animals and humans. *The Sydney Morning Herald* published stories on the devastation from the 16 to 20 December 1944. Klepac (1996 p. 79), in his biography of the artist Sir Russell Drysdale, suggests that until 1944, wartime censorship had prevented publication of 'the details of this natural disaster' and 'now that wartime news censorship had been lifted, the press decided to let the public know what was happening to the land out west'. The articles drew an immediate response from the Premier, W. McKell defending the government's policy on conservation. Letters to the paper continued the debate as to the causes of such devastation until the outbreak of the Battle of the Bulge returned the public's attention to the war.

Stock losses

The effect on animal numbers was equally dramatic. Stock numbers were reduced in 1944 and 1945 to 20–60% of the previous period. Ker Conway (1989) reports that they were already down to half the usual stock number in late summer of 1944 with most of the older sheep too weak to be shorn in June 1944. By winter 1945 the 'last of the sheep began to die by the hundreds' (p. 76). In 1945 stock numbers for the

Western Division of New South Wales reached the lowest on record (since 1903). Stock numbers declined from 7,117,000 in 1943 to 3,917,500 in 1945. Similarly in South Australia, Donovan (1995, p. 92) cites South Australian Parliamentary papers that recorded the problems faced by the South Australia Pastoral Board:

> The industry has suffered extremely heavy losses in stock; in some cases whole flocks have been wiped out, and in others up to 75% are common losses. The position was aggravated by the widespread nature of the drought, with no relief country or sale for store stock, with the consequence that they were left to take their chance or were destroyed on the property. Further loss has been incurred by the serious erosion menace in drifting up fences and dams, which will necessitate much expenditure to make them serviceable again.
>
> The most serious and irreparable damage, however, has been done to the country itself in the further elimination of permanent fodder plants such as salt, blue and other bushes which only nature can replace. This latter is one of the most complex problems of the Board, whose policy is to induce pastoralists to preserve and promote growth of permanent plants for their own advantage against such seasons as we have just gone through. Unfortunately pastoralists have not been able to give much cooperation during years like the past where they have had to call on every reserve to tide them over this lean period, and nature certainly has not helped the Board unless it has forced landholders to view the erosion problem in its right perspective, which the Board feels sure it has.

Nor were properties that were conservatively grazed immune from the devastation. A South Australian grazier (Honner 1946, p. 130) documented how dust storms 'blasted' his annual and perennial vegetation destroying its value for grazing.

Through Russell Drysdale's paintings, Episode 4 has left a lasting visual image of devastation (e.g. Plate 2.4c,d). One particular painting, 'The Crucifixion', was regarded as the 'peak of Drysdale's pictorial study of soil erosion'. It suggested 'the soil of Australia crucified on the cross of erosion' (Bonyhady 1997), and created a controversy regarding the cause of soil erosion – natural or man-made. It was suggested that the painting not be exhibited overseas (Bonyhady 1997).

The rapidity of the collapse of vegetation cover and surface soil protection suggests that considerable damage had already been done to perennial vegetation through the droughts of the 1930s and early 1940s. In addition to economic forces leading to high stocking rates, high grazing pressure was also amplified by 'rabbit plagues' during the 1930s causing 'rabbit droughts' (R. Rees pers. comm.). Thus the time series (Figure 2.4) suggest an unrelenting grazing pressure on perennial vegetation during intermittent droughts eventually resulted in collapse when consecutive dry years 1943 and 1944 occurred.

Recovery?

Substantial rainfall occurred in 1946 to 1947 and 1949 to 1950. Stock numbers had returned by 1947 to 80–90% of the previous period but did not return to above 1943 levels until 1954 following the exceptionally wet seasons and reduction of rabbit numbers.

Despite the apparent 'devastation' of the mid 1940s, there was a dramatic change over the next 40 years which 'can only be regarded as remarkable, occurring as it did while the land continued to be used at normal stocking levels for grazing' (Palmer 1991, p. 8).

Condon (1986a, p. 39) provided a very assertive view as follows:

> In a paper under preparation, the author has listed 40 sites known to him in the early 1950s, as catastrophically eroded, or confirmed as such by present evidence of drifted up fences and deep scalds, or written accounts. All have undergone near-complete reclamation, or are in the process, their former extent being marked by the difference of 20–50 cms between eroded [but now recovered, R.W. Condon pers. comm.] residuals and boundary areas.

> In the face of such obvious reclamation of catastrophic erosion, it cannot be assumed that adjoining non-eroded country is deteriorating in condition (other than the country being invaded by scrub). In these circumstances, it is difficult to be patient with those who claim the country is being overstocked (the evidence suggests the opposite). No doubt, such attitudes arise from a misunderstanding of what overstocking is, encouraged by the fantasy embodied in statistics presented for western New South Wales in the Commonwealth's State Governments Collaborative Soil Conservation Study (DEHCD 1978). The huge areas described as requiring treatment and/or management practices may have been true of the condition of the country during the 1965–1967 drought, but certainly not today, nor in the 1979–82 drought.

As indicated in Chapter 1, Condon (1986c) attributed the recovery to:

1. improved rainfall regime in the 1950s and 1970s and reduced wind strength (Ward and Russell 1980);
2. reduction in rabbit numbers;
3. breaking up of large stations reducing grazing pressure on woolsheds and water points;
4. 1950s wool boom providing money for fencing and more watering points;
5. road transport allowing stock to be moved rapidly in time of drought;
6. government drought relief schemes encouraging early destocking;
7. awareness of the effects of resource over-use especially under dry conditions; and
8. security of tenure providing incentive for property development.

However, this view of remarkable recovery is not universally held (e.g. White 1997, p.90). The lack of objective assessment of resource condition has been a major problem for determining trends in grazing lands. The survey of degradation in New South Wales in 1988 was designed to provide such a benchmark survey (Chapter 1, Table 1.6). Subsequent surveys will hopefully quantify the trends in resource condition. The exceptionally wet period of the 1950s not only brought improvement but also woody weeds – Episode 5.

The causes of recovery have also been a subject of debate. Whilst both Condon (1986c) and Palmer (1991) attributed recovery to many factors, Pickard (1993) in his analysis concluded that 'increased rainfall since the late 1940s and the demise of the rabbit' were the major reasons for recovery, and that all other causes were 'incidental or only added a relatively small increment' to improve condition. Pickard (1993) drew attention to the conclusion of the Royal Commission of 1901 that 'drought is the predominant characteristic of the west, and not merely an enemy to be occasionally encountered'. He somewhat despondently, stated that 'even after the prolonged droughts of the mid 1960s, the early 1980s and now the early 1990s, many graziers do not accept this conclusion'.

Last words

In the foreword to Beadle's seminal review the Minister for Conservation, the Honourable George Weir considered the need for remedial action in 1948:

> The problem of maintaining or regenerating this vegetation is intimately associated with grazing management, embracing, as it does, effective rabbit control and judicious stocking.
>
> I regard bush fires, overstocking, and the failure to deal with rabbits, as vegetation's greatest man-made enemies and erosion's most effective allies. Droughts, of course, man cannot control.
>
> . . . .
>
> In my opinion, western erosion could be gradually minimised – if not entirely banished – by the removal of all stock for a limited period and the eradication of rabbits, thus allowing mother nature to operate and exercise her beneficent influence.

> However, because such a drastic measure may be regarded as defeatist and entail the temporary sacrifice of a pioneering and reasonably successful rural economy, which has been built up around these grazing lands, our object becomes twofold. We must, perforce, maintain our pastoral and allied industries, and simultaneously improve our vegetative cover throughout.

Ker Conway (1989, p. 82) wrote regarding her feelings as she and her mother left their property in August 1945:

> I did not understand the nature of the ecological disaster which had transformed my world, or that we ourselves had been agents as well as participants in our own catastrophe. I just knew that we had been defeated by the fury of the elements, a fury that I could not see we had earned.

What do we learn for preventing land and pasture degradation?

1. Episode 4 shows the potential for the combination of drought, lack of vegetation cover and high winds to cause substantial soil erosion.
2. The relative attribution of apparent recovery to inter-decadal climate fluctuations, government policy, financial success, rabbit control, and adoption of better grazing practices is difficult. We suggest that the remarkable recovery in the 1950s and 1970s is directly linked to the sequence of above-average rainfall years associated with the combination of La Niña and *cool* IPO periods.

2.6 Episode 5: Western New South Wales in the 1950s

Episode 5 involved the infestation of woody weeds in the Cobar–Byrock region of New South Wales (Anon. 1969) during the wet 1950s. Thus it differs from previous episodes that have mainly concentrated on the loss of perennial species and soil erosion due to drought and high grazing pressure. The impact of the infestation was revealed subsequently during the dry and drought years of the 1960s resulting in a major government report to the New South Wales Minister of Lands (Anon. 1969).

The degradation episode was driven by the sequence of wet years that resulted in: (a) the widespread death of rabbits with mosquito-driven spread of myxoma virus; (b) the germination and establishment of woody weeds; and (c) lack of prescribed burning to control woody weeds (Anon. 1969).

Climate history

Table 2.6 shows the 30–year history from 1947/48 to 1976/77 covering the wet 1950s and the extended drought period from 1964/65 to 1967/68; and Plate 2.6 shows the 20–year period from 1947/48 to 1966/67. The episode involved the germination and establishment of a wave of woody weeds (Anon. 1969), and hence the extended wet period of the 1950s before the 1960s drought episode is shown in Table 2.6. During the 'wet' period La Niña years (1947/48, 1950/51, 1955/56, 1956/57) resulted in average to well above-average rainfall. In addition the neutral SOI years from 1948 to 1954 were generally above-average (1948/49, 1949/50, 1954/55). Similarly the El Niño year of 1953/54 did not have a substantial rainfall deficit. Thus the period 1947/48 to 1956/57 was generally well above-average providing suitable conditions for vegetation growth, woody weed establishment and bushfires. The subsequent period included three El Niño years (1957/58, 1963/64, 1965/66) with substantial rainfall deficiency occurring in two of these years (1957/58 and 1965/66). The La Niña year 1964/65 had generally below-average rainfall across much of western New South Wales and Queensland, and was the only La Niña year in the extended drought/degradation sequences in eastern Australia (Table 1.3).

The IPO 'index' was very *cool* from the late 1940s to 1959 and slightly *cool* for the early 1960s up to 1967. Thus the extended wet period of the 1950s is consistent with what has occurred in other periods when the IPO 'index' has been very *cool*, e.g. early 1890s and mid 1970s.

Table 2.6 Extended drought period (brown) during regional degradation Episode 5 in western New South Wales. The extended drought period was calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12–month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5). The year 1951/52 has been indicated as an 'El Niño' year based on SST and SOI indicators other than the official SOI. Years in the table are indicated only by the starting year, i.e. 1947 is the period 1 April 1947 to 31 March 1948, referred to in the text as 1947/48).

Episode	Rainfall Anomaly										
Episode 5 Western NSW	Year	**1947**	**1948**	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**	**1955**	**1956**
	% Anomaly	-1	+20	+40	+15	-22	+10	-11	+23	+114	+12
	Year	**1957**	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**
	% Anomaly	-42	+17	-20	-17	+26	+19	-19	-34	-37	-15
	Year	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**
	% Anomaly	-33	23	-32	+20	-11	-22	+136	+53	+99	-4

Data sources and chronology

Time-series of stock numbers for properties in the Cobar–Byrock district with a range of scrub densities were given in Anon. (1969). The stock numbers were three–year moving averages to 'illustrate trends more clearly' (Anon. 1969). Pasture growth was simulated for 'perennial grass' using a low shrub density (Figure 2.5). High rainfall and pasture growth occurred from 1950 to 1956. From 1957 onwards, reduced rainfall resulted in low pasture growth and decline in stock numbers.

Observations and analysis

On 29 February 1968, the New South Wales Minister for Lands established an interdepartmental committee to 'investigate and report on the problem of scrub and timber regrowth'. The following quotes come from the Report of the Interdepartmental Committee on Scrub and Timber Regrowth in the Cobar–Byrock district and other areas in the Western Division of New South Wales, February 1969. They are reproduced at length because of their definitive statements and analysis and their wider implications for current vegetation thickening (Burrows 1995, Burrows *et al.* 2002). The Committee's review of the history of the scrub problem identified two major pulses of infestation: 1890s and 1950s (Anon. 1969, p. 13):

> This country was first settled in the 1870s and much ringbarking and clearing has been carried out in the intervening years. During this period two major invasions of scrub and timber regrowth have taken place.
>
> In the 1890s, following a prolonged period of well above average rainfall, much of the earlier developmental work was nullified by a rapid increase in the natural timber and shrub species. The Royal Commission of 1901, which enquired into the depression in the Western Division at that time, made special mention of the problem as one of the major causes of the depression in the Cobar district.
>
> This extensive regeneration of scrub and timber caused a marked reduction in the grazing capacity of the country and was followed by a prolonged drought accompanied by a serious fall in prices for pastoral products.
>
> The Royal Commission also considered the absence of bushfires subsequent to the occupation by the early settlers to be a major reason for increase in scrub and timber regrowth. It was pointed out that prior to settlement, regrowth was kept under control by occasional bushfires.
>
> An extensive bushfire in 1921, covering thousands of square miles, from near Louth on the Darling River towards Nyngan on the Bogan River destroyed much of the timber and scrub which had appeared in the 1880s and 1890s. It is probable that during the years following there would have been a gradual return of scrub and timber, with thick invasions in localised areas in response to exceptional rains or other factors.

> The second major regrowth of scrub and timber took place in the 1950s as the result of another prolonged period of above-average rainfall. This has also been followed by a prolonged drought period. Drought-breaking rains in January, 1968, with good follow-up rains in May have brought little response to country affected by timber and scrub regrowth. Country assessed at one sheep to 10 to 15 acres in the late 1940s and early 1950s can now carry only one sheep to 15 to 20 acres and in some cases even less.
>
> The Committee considers that scrub and timber regrowth which has plagued the Cobar–Byrock district since its occupation by white man is not due to any particular factor. Rather it is a natural feature of the environment occurring as the result of a combination of several factors, and accentuated by the absence of natural fires.

The Committee examined the possible causes of woody regrowth, in particular addressing the issue of when the problem became apparent as distinct from when it was caused (p. 65):

> In attempting to establish a cause [for timber and scrub regrowth], it is well to appreciate that the species contributing to the problem are part of the natural environment. An increase in the density is a natural response to the above average rainfall between 1950 and 1956. The rainfall in these two particular years was more than double the average and the soil was wet for months on end. Most other years in this period recorded above average rainfall. Much of the present timber and scrub regrowth can, by reason of tree size, be traced to these years. 1962 was also a year in which rainfall exceeded 20 inches and in which much regeneration of scrub and timber occurred.
>
> The appearance of scrub did not, however, make its presence felt until the ground forage, which had grown tall during the years of high rainfall, was reduced by grazing as dry conditions prevailed throughout 1957. As the grass and herbage was eaten out, the seedlings and saplings of regenerating scrub and timber became obvious.

The Committee reviewed the impact of the infestation on graziers as revealed during the dry and drought years of the 1960s (p. 55):

> Most affected settlers report having had no reasonable feed since 1962. Many regard 1957 as the last year in which reasonable feed was available. (p. 55)

And later (p. 56):

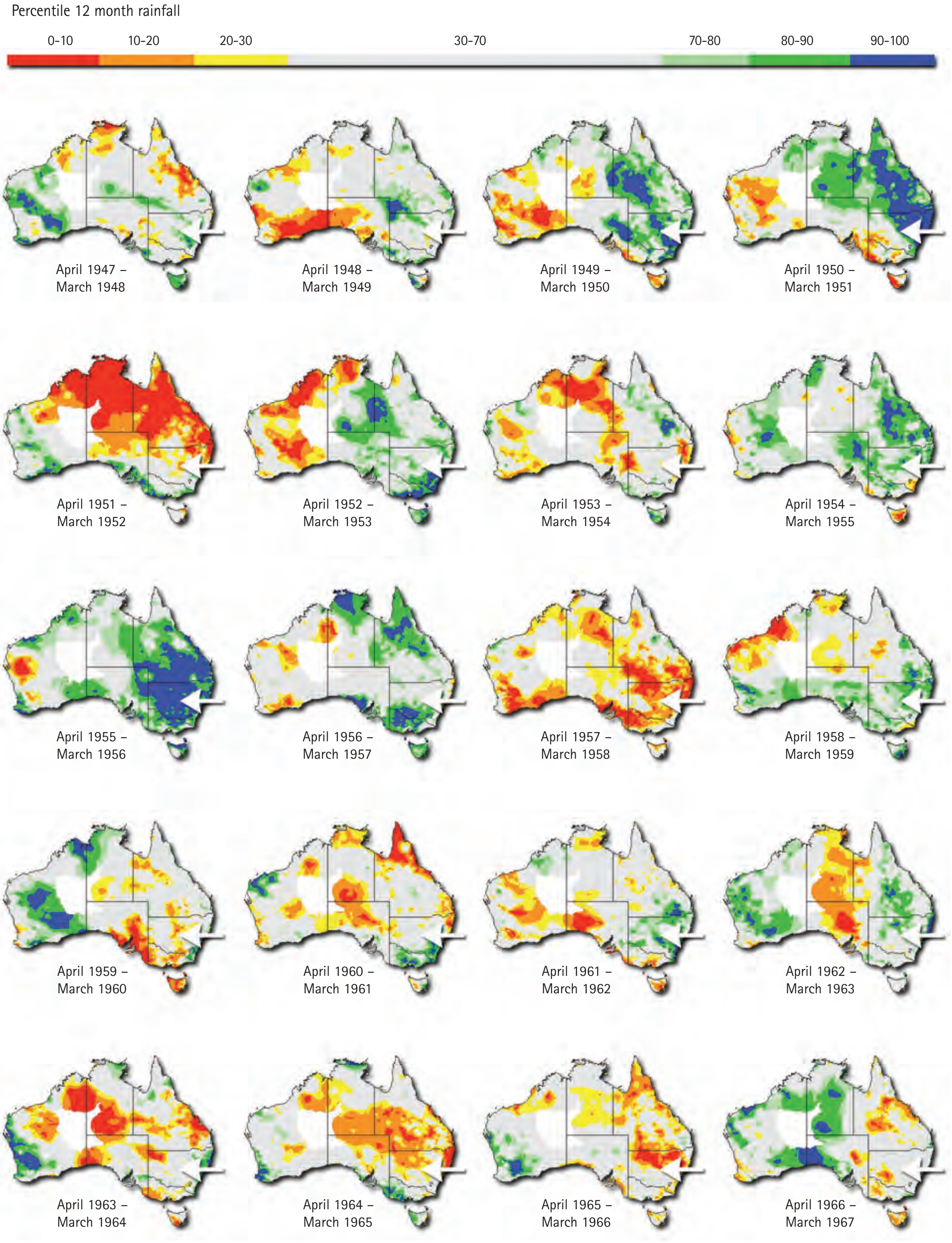
> The severity of the problem of scrub and timber regrowth may be gauged from the almost complete lack of response to the 8 to 12 inches of rainfall received for the first 5 months of 1968. The country affected by thick scrub is still in the grip of the drought which has prevailed since 1965. Some of this land was re-allotted for settlement in the early 1950s, being assessed at, and able to carry, in excess of 3,000 sheep. However, some blocks severely affected by the scrub problem cannot now carry 2,000 sheep on 50,000 acres, in spite of constant lopping of scrub. One settler reported that he had been engaged in lopping scrub for more than 80 of the last 123 months.

The impact of woody weed invasion was shown by comparing four properties with different soils and scrub problems (Anon. 1969). Stock numbers (actual data not shown) were calculated using a three–year moving average to show the overall trends relative to the longer-term means for each property. We quote at length from the Committee's analysis of these data (p. 57):

> Carrying capacity of Holding [property] A, in a district with an average rainfall of 11 inches, is higher than the carrying capacity of the holdings in districts with average annual rainfall some 2 to 3 inches higher. This is a reflection on the effect of the almost treeless condition of Holding A compared with the other three holdings.
>
> The carrying capacities of Holdings A and B, which are reasonably free of scrub, reflect the influence of good rainfalls much more closely than Holdings C and D. The stocking figures for Holdings A and B remain at a relatively constant level, showing rises and falls corresponding closely with seasonal conditions.
>
> Holding D, which is on hard red country with serious infestation of scrub and timber regrowth in the 1950's, shows a similar trend, but with a gradual decline in which each peak and trough is lower than the preceding one.

Episode 5

Western New South Wales 1948-1967



April 1947 – March 1948

April 1948 – March 1949

April 1949 – March 1950

April 1950 – March 1951

April 1951 – March 1952

April 1952 – March 1953

April 1953 – March 1954

April 1954 – March 1955

April 1955 – March 1956

April 1956 – March 1957

April 1957 – March 1958

April 1958 – March 1959

April 1959 – March 1960

April 1960 – March 1961

April 1961 – March 1962

April 1962 – March 1963

April 1963 – March 1964

April 1964 – March 1965

April 1965 – March 1966

April 1966 – March 1967

Plate 2.6 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 5. The El Niño years were 1951/52, 1953/54, 1957/58, 1963/64, 1965/66. The La Niña years were 1947/48, 1950/51, 1955/56, 1956/57, 1964/65.

Episode 5 – Western New South Wales 1950s

Time period: 1948 to 1968
Base period: 1951 to 1956

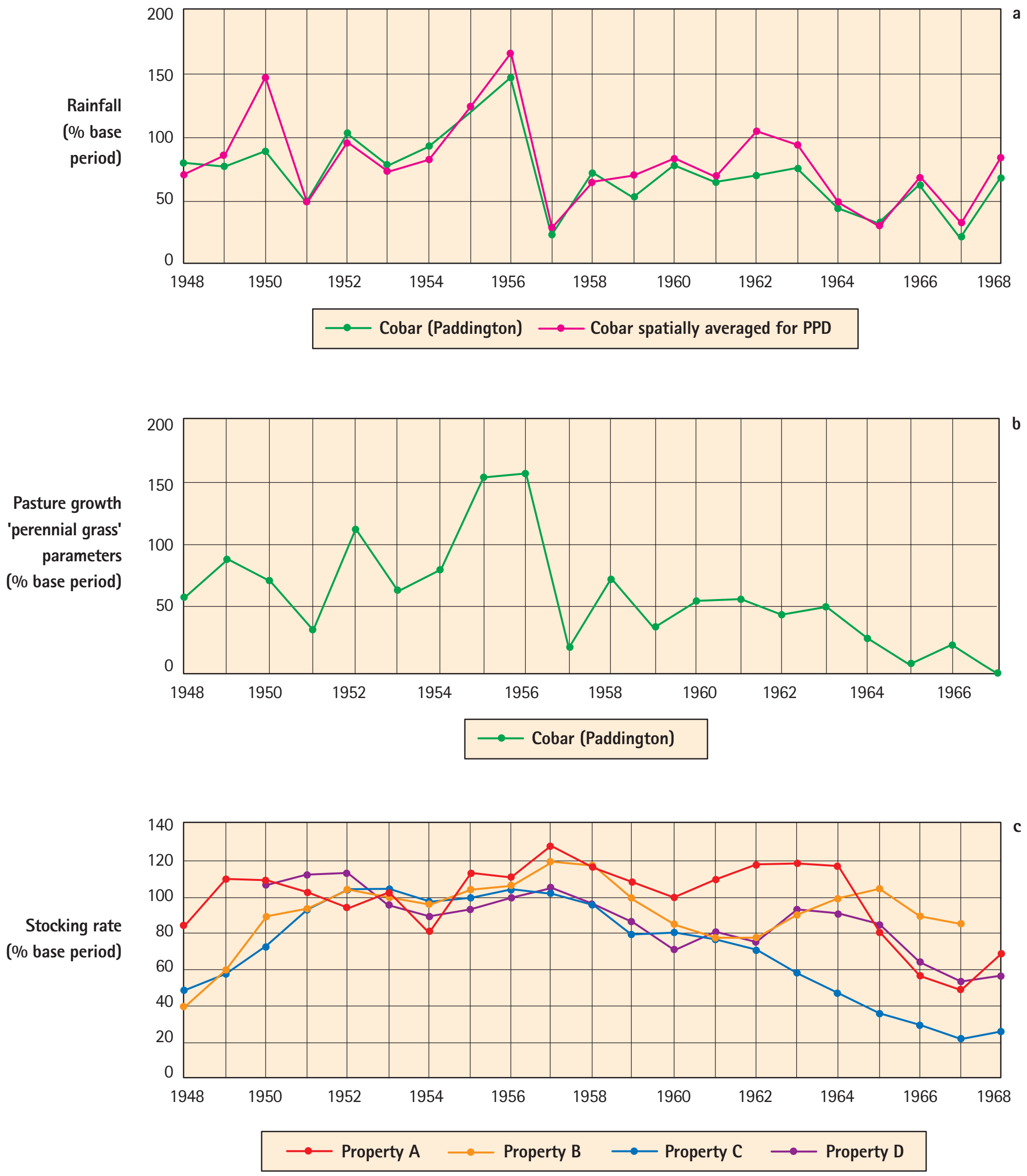


Figure 2.5 Episode 5 for western New South Wales in the 1950s. Time series of: (a) rainfall; (b) simulated pasture growth using 'perennial grass' parameter set; and (c) reported stock numbers. The annual period is 1 January to 31 December. Data are expressed as a percentage of the mean of the base period 1951 to 1956. The details of properties A–D shown in (c) (quoted directly from Anon. 1969, p. 59) are:

Property A on Class IV Country – Calcareous sandy loams with open belah rosewood and mulga.
Average rainfall 11.0 ins. Average carrying capacity 1936-62 is 10.4 sheep/100 acres (eq. 1 per 9.6 ac).
Property B on Class V – Soft red country. Brown sandy loams with open pine bimble box and red box.
Average rainfall 13.75 ins. Average carrying capacity 1936-62 is 8.5 sheep/100 acres (eq.1 per 11.8 ac)
Property C on Class VI – Hard red country. Red brown loams with thick timber and scrub. Average rainfall 13.80 ins.
Average carrying capacity 1936-62 is 11.0 sheep/100 acres (eq. 1 per 9.1 ac)
Property D on Class VI – Hard red country. Red brown loams with thick timber and scrub. Average rainfall 14.25 ins.
Average carrying capacity 1947-62 is 7.3 sheep/100 acres (eq. 1 per 13.7 ac)

> Holding C is also on hard red country on which there has been a heavy invasion of scrub species in the 1950's. The graph shows a continuous decline in stock numbers after 1956, with no response to the increasing rainfall culminating in the rainfall peak shown for 1963. The commencement of the steep decline in 1957 coincides with the period when the scrub and timber regrowth would have been making its presence felt. The continuous steep decline indicates serious overgrazing of the pastures as the competition from scrub and timber begins to take effect.
>
> Figures for 1968 show very clearly a marked upward trend for Holding A and a much lesser upward trend in the case of Holdings C and D indicate the poor recovery of scrub affected holdings followed the drought. Figures for Holding B for 1968 are not available.
>
> Thus, it is apparent that the decline in productivity in the Cobar district will not be alleviated by a series of favourable seasons. Indeed, should this occur, the scrub and erosion problems could become rapidly worse.

The Committee concluded (p. 66) that the ideal growing conditions of the 1950s and the absence of fire were the causes of the infestation:

> For widespread regeneration of any particular species to take place, ... the conditions were met by the period of excessively high rainfall during the period commencing late in 1949, continuing right through the whole of 1950, and repeated in the autumn and winter of 1952. The years 1953 and 1954 were both slightly above average, 1955 was well above average while 1956 was a year in which the soil was in a saturated condition throughout the whole year. The long-term average annual rainfall for Cobar from 1882 to 1965 is 14.18 inches. The average for the 7 years from 1950 to 1956 inclusive was 20.02 inches. Only in 1951 was the annual rainfall below the long-term average of 14.18 inches. There can be little doubt that this long period of very high rainfall is a major factor in the invasion of scrub and timber.

And later:

> Rather than search further for factors causing timber and scrub regrowth, it may be more realistic to regard this as a natural feature of the environment, and seek a reason why there are 'open' areas not unduly affected by timber and scrub regrowth. Except for those areas cleared by man, the obvious answer is fire
>
> Evidence given to the Royal Commission in 1901, and the Commission's report, emphasised the place of bush fires as a natural feature of the environment in keeping the country free of scrub. Bush fires swept the Cobar district in 1921 over hundreds of miles wide from Louth to the Bogan River. These fires would have destroyed much of the scrub referred to in the Royal Commission's report. A recent fire covering a relatively small area north of the railway line near Canbelego has had a similar effect.

The Committee also examined other possible causes for the rapid woody weed expansion. The elimination of rabbits in the 1950s by myxomatosis was one factor put forward. However, the scrub infestation of the 1890s had coincided with periods of very heavy rabbit and stock numbers. The Committee concluded that the exceptional wet period of the 1950s provided the appropriate conditions for scrub and timber regeneration and the absence of fire allowed these woody plant seedlings to survive and out-compete 'ground forage'.

Thus the 1950s would have required a rapid change in the attitude to use of pasture as fuel rather than as feed! Given the devastating experience of the droughts of the mid 1940s it is understandable that graziers may have been cautious in the use of the drought reserve and regarded the abundance of fuel more as a fire hazard to be grazed off rather than as a means to enable control of another wave of woody weeds. By the time the effects were apparent in 1957 it was too late.

Hodgkinson *et al.* (1984, p. 150) describe the results of a computer simulation evaluating the financial cost of not burning in 1956 after the wet period and prior to the onset of dry conditions (1957).

> In the case [simulated], 25% of the property was burnt before the drought was apparent and this led to drastic reductions in stock. Stock numbers did not recover to normal levels for three years after the fire, and income

> took four years to recover. On the other hand, if another very wet year had been experienced after the fire no substantial loss of grazing capacity would have occurred. Failure to burn in 1956 allowed shrubs to establish and five years later they began to cause a decline in carrying capacity. The full effects of this establishment occurred 15 years later in 1971 and the loss from not burning then became substantial.

The results of the simulations of Hodgkinson *et al.* (1984) highlight the dilemma for graziers caused by climatic variability. Burning is required for woody weed control but reduces feed availability should drought follow as occurred in 1957.

Recovery?

R.W. Condon (pers. comm.) who was principal author of Anon. (1969) provided the following recent observation:

> Having travelled through much of the Cobar scrub country from the south west and to the east and south east … in August 2002 and from Nyngan to Bourke and Brewarrina to Nyngan in recent years, I can guarantee there is no recovery in terms of tree and shrub death - only more generations of scrub species from the 1980s and 1990s generations in-filling previous generations of scrub cover.

He was also surprised to see more grass cover 'albeit light and sparse under dense scrub where there would have been nothing in earlier years'. He suggested that the scrub cover was now 'so thick that there is enough leaf fall to improve the "ecosystem function" sufficiently to allow some infiltration into formerly eroded surfaces to enable grasses and some herbage to get established in patches.'

Satellite-derived maps (Carter *et al.* 1996) show the persistence of high tree/shrub density into the 1990s (Plate 2.7). Similarly, the 1987/88 benchmark land degradation survey of New South Wales identified substantial areas of western New South Wales with minor (29.2%), moderate (27.3%), and severe (10.3%) woody shrub infestation (Graham *et al.* 1989, p. 22). The authors stated:

> Woody shrubs (woody weeds) are inedible native plants that are rapidly infesting large areas of the semi-arid and arid regions of NSW. Their distribution and density are increasing owing to favourable environmental conditions and lower incidence of fire.

What do we learn for preventing land and pasture degradation?

1. Sequences of above-average years whilst providing much-needed recovery (Episode 4) can also initiate substantial and undesirable vegetation changes. Whether comparable changes may possibly also occur in the future as a result of increases in temperature and carbon dioxide and the response of different plant species to these variables in natural systems is an area of active research. Thus the continued monitoring of vegetation is required to detect such changes so that appropriate management actions can be taken before it is too late.

2. Episode 5 is an example of what happens when a management change (removal of fire) is combined with an infrequent climatic sequence.

3. The suggested link between several above-average rainfall seasons and pulses of woody weed establishment (e.g. Booth and Barker 1981) also supports the importance of these climatic periods as opportunities for recovery of 'desirable' perennial species.

4. SOI– or ENSO-based seasonal forecasting systems provide some skill in forecasting some of the wet years of the type that occurred in the 1890s, 1950s and 1970s. The linking of climate forecasts to the decision to burn pasture in order to control woody plants may remove some of the uncertainty faced by graziers who are concerned about the risk of drought following fire.

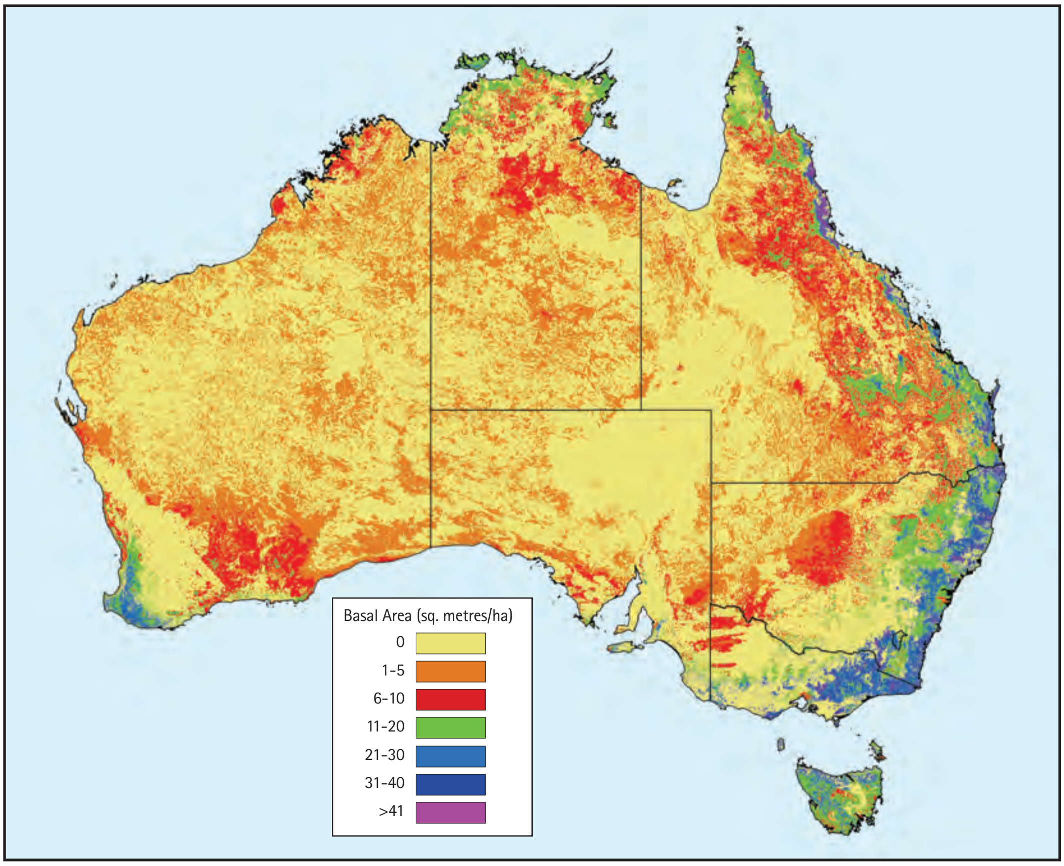


Plate 2.7. Tree basal area map of Australia (Carter *et al.* 1996) highlighting the persistence of high tree/shrub density in western New South Wales into the 1990s.

2.7 Episode 6: Central Australia in the 1960s

Central Australia experienced a long and severe drought from the late 1950s to 1965/66. Beef cattle numbers had almost doubled since 1946 (Condon *et al.* 1969a, Friedel *et al.* 1990) during the above-average rainfall conditions of the 1950s. Commencing in 1958 the combination of high stock numbers and low rainfall resulted in 'denudation of natural vegetation' (Chippendale 1963, p. 84) and government concern regarding 'over-stocking and over-grazing, pasture degeneration and soil erosion' (Richardson *et al.* 1964, p. 4). The drought precipitated a substantial reduction in stock numbers below 1946 levels. R. Condon, G. Cunningham and J. Newman of the New South Wales Soil Conservation Service were asked to report on 'erosion problems arising from the prolonged drought, and on necessary restorative measures' (Condon *et al.* 1969a, p. 49). Drawing on their New South Wales experience, R. Condon and colleagues developed a quantitative approach for estimating safe carrying capacity for properties in central Australia and western New South Wales (Condon 1968). In the mid 1970s 'exceptional rainfall' occurred in central Australia. The favourable seasonal conditions and low cattle prices (Figure 1.7) resulted in cattle numbers increasing to levels unprecedented in central Australia (Bastin *et al.* 1983, Griffin and Friedel 1985) raising concern regarding the possible threat of another degradation episode should drought return (Bastin *et al.* 1983). With the return of better prices and the drier conditions of the 1980s, stock numbers declined by 30% (Friedel *et al.* 1990). In 1993 to 1995, G. Cunningham returned at the invitation of the Centralian Land Management Association and re-surveyed rangeland sites in the Alice Springs area documenting where recovery had occurred.

Climate history

Table 2.7 shows the 30–year period from 1945/46 to 1974/75 spanning the extended drought period from 1958/59 to 1965/66. Plate 2.8 shows the 20 years from 1954/55 to 1973/74. The period from 1945/46 to 1957/58 was one of large year-to-year variations in rainfall with individual years of severe rainfall deficiency followed by well above-average rainfall, e.g. 1949/50 to 1953/54 (Table 2.7). The period 1954/55 to 1957/58 had average rainfall. The La Niña years of 1947/48, 1950/51, 1955/56 contributed to the favourable conditions before 1957. In 1958/59 a devastating drought period commenced, with the extended drought period lasting eight years from 1958/59 to 1965/66 with major drought-breaking rains in 1966/67 and 1968/69. The early to mid 1970s were characterised by years of extremely high rainfall (Figure 1.1g) in 1973/74, 1974/75, 1975/76 (not shown) also associated with several La Niña years.

In the period 1945/46 to 1957/58, the four El Niño years (1946/47, 1951/52, 1953/54, 1957/58) had below-average rainfall but were not as severe as subsequent El Niño years (1963/64, 1965/66, 1969/70, 1972/73). Thus, the El Niño years of 1963/64 and 1965/66 contributed to extending the drought period that started in 1958/59. As indicated in the previous episode, the La Niña year of 1964/65 had severe rainfall deficiency and did not break the drought.

The IPO index was very *cool* during the 1950s and early 1970s and the average to above-average rainfall that occurred in central Australia suggests that the influence of the IPO might extend westward at least as far as central Australia in some years (Chapter 1, Plate 1.4b).

Table 2.7 Extended drought period (brown) during regional degradation Episode 6 in central Australia. The extended drought period was calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12–month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was below 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, El Niño years were SOI ≤ –5.5, La Niña years were SOI ≥ +5.5). The year 1951/52 has been indicated as an ' El Niño' year based on SST and SOI indicators other than the official SOI. Years in the table are indicated only by the starting year, i.e. 1945 is the period 1 April 1945 to 31 March 1946, referred to in the text as 1945/46.

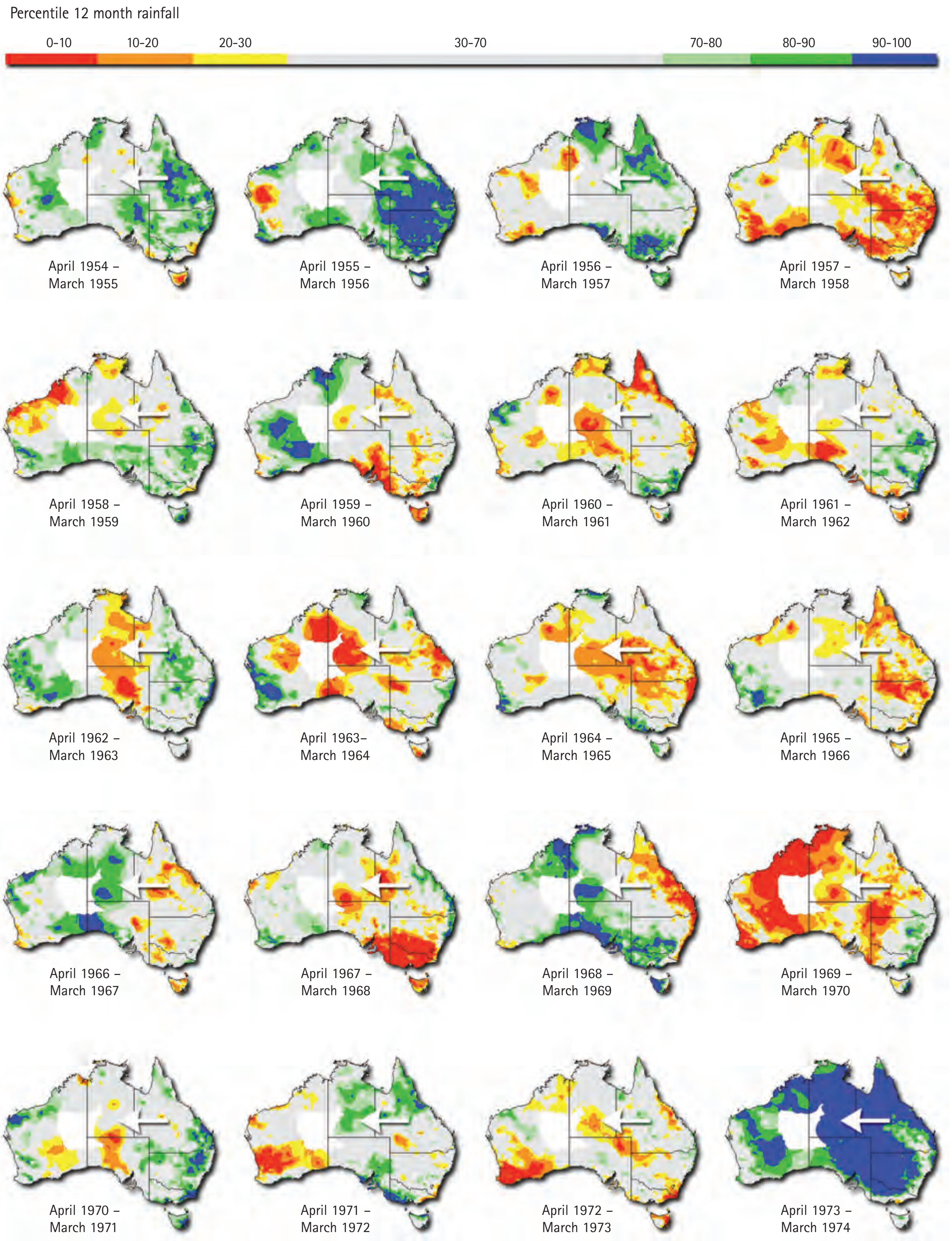
Episode	Rainfall Anomaly										
Episode 6 Central Australia	Year	**1945**	**1946**	**1947**	**1948**	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**
	% Anomaly	+16	-22	+37	-20	-49	+66	-54	+48	-25	+6
	Year	**1955**	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**
	% Anomaly	+3	-15	-10	-37	-31	-56	-28	-48	-63	-57
	Year	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
	% Anomaly	-36	+82	-45	+84	-54	-31	+34	-57	+234	+105

Data sources and chronology

Animal numbers for central Australia are from Condon *et al.* (1969a). Pasture growth simulations were based on two parameter sets: (a) central Australian 'herbage' calibrated and validated from Hobbs *et al.* (1994); and (b) 'perennial grass' (not calibrated or validated for the central Australian region). The latter parameter set, although not validated in the region, provides a plausible but conservative indication of perennial grass growth with dynamic grass basal cover (Figure 2.6).

Rainfall records for selected stations (Figure 2.6) showed low year-to-year variability from 1953/54 to 1959/60, and then was followed in 1960/61 to 1964/65 by a substantial decline to 20–80% of the previous period. First-hand accounts (J.R. Purvis) and pasture growth simulations indicated that from 1956/57 to

Episode 6
Central Australia 1955–1974



April 1954 – March 1955
April 1955 – March 1956
April 1956 – March 1957
April 1957 – March 1958
April 1958 – March 1959
April 1959 – March 1960
April 1960 – March 1961
April 1961 – March 1962
April 1962 – March 1963
April 1963– March 1964
April 1964 – March 1965
April 1965 – March 1966
April 1966 – March 1967
April 1967 – March 1968
April 1968 – March 1969
April 1969 – March 1970
April 1970 – March 1971
April 1971 – March 1972
April 1972 – March 1973
April 1973 – March 1974

Plate 2.8 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 6. The El Niño years were 1957/58, 1963/64, 1965/66, 1969/70, 1972/73. The La Niña years were 1955/56, 1956/57, 1964/65, 1970/71, 1971/72, 1973/74.

1959/60 plant growth fell to 60–80% of average growth for the base period (1953/54 to 1957/58). The subsequent drought period 1960/61 to 1964/65 had lower pasture growth (40–60% of the previous base period). Cattle numbers declined gradually from the peak in 1957/58 to 40% of the base period in 1964/65.

Observations and analysis

A grazier, J.R. Purvis (pers. comm.), has described the unfolding of the drought, providing comments at the time as well as his own review of this experience with the benefit of hindsight. From this experience he adopted conservative stocking practices and embarked on the restoration of his property with particular attention to retaining runoff. His comments follow:

> *Comments written – end of 1956:* Fairly good season. Trucked 300 bullocks. Sold 670 cows & calves. Grass dried off badly about Christmas because of terrific weather.
>
> *Hindsight:* These cattle were on Woodgreen. Herd of 3000 or more on land that today we are trying to sustain 300. Disaster was coming.
>
> *Comments 1957:* Early part of year was dry and cattle lost condition. The winter rain brought an enormous amount of herbage and cattle did well on it. Trucked 350 bullocks in early winter. They did not benefit from the rain as it was early when they left. Some were fat but mostly in store condition and hungry after being mustered. Trucked 150 steers and bullocks in September. They were fat and some prime. Struck 3 bad markets and they sold poorly. By the end of the year we were into a drought. The rain in December did very little good as the country was already bare and the little bit of grass that came up was soon burnt off.
>
> *Hindsight:* Woodgreen had reached its biggest herd ever around 4000. Man-made drought.

In hindsight, J.R. Purvis stated that it was a 'man-made' drought. He commented (Purvis 1986, p. 111) that both his father and the relevant government agency grossly overestimated the carrying capacity of the country. The cause of the overestimate was the biased view derived from the productivity of the smaller areas of good country, ' a gross misunderstanding of how arid zone pastures worked' (p. 111).

> *Comments 1958:* The worst year in living memory of the run. Cattle started to die about May. By October I had dragged 200 away from bores. I stopped counting then but they died right through the summer until May 1959. The highest number dying in November–December Hardly any calves left alive by May 1959. At a guess it was 700 (out of 3000). We were able to save a few hundred of the weaker ones by shifting them to Auyda (a bore sunk in spinifex country while mustering them to shift) which we completed in December. We slaved most of the year but nothing we did seemed to alleviate the suffering of the stock. In May 1959 we had to cut mulga down to feed stock around Southgate (losing all but 9 plant horses). Dust storm after dust storm until March 1959 when a bit of rain settled it. The cattle on the west side were better off than those on the station side. Due mostly to spinifex.
>
> *Hindsight:* At least 1000 head died then. We do not use spinifex country today as we know it is always below maintenance diet. The fact is we should never have had the cattle. The minimum stocking rate for Woodgreen had been specified as 3000.
>
> *Comments 1959:* Shifted several lots of cattle to Auyda and by doing so saved them. By the end of May the country was a little better, as the spinifex had freshened up and the cattle were improving. Sold 350 cows, steers and calves early in May. They all came from the west side of the run making room for the poorer cattle which we shifted from the station side. Sold 75 steers in August. £24 on trucks the best sale of steers we have ever had. They were in strong condition. During the latter part of the year the cattle started to get poor again, but by December we had had no losses. The last 7 months of the year were the driest on record. The drought is still on but generally speaking I don't think this year was as bad as last. There have been a few dust storms, but so far there has not been a bad one. We have not branded any horses for nearly two years nor have there been any strong enough to break in.
>
> *Comments 1960*: Rain fell where it was most needed and therefore it was a better year than the amount of rain would indicate. Sold approx. 500 cattle: 288 steers to Deep Well early in year and 317 to a South Australian

Episode 6 – Central Australia 1960s

Time period: 1954 to 1974
Base period: 1954 to 1958

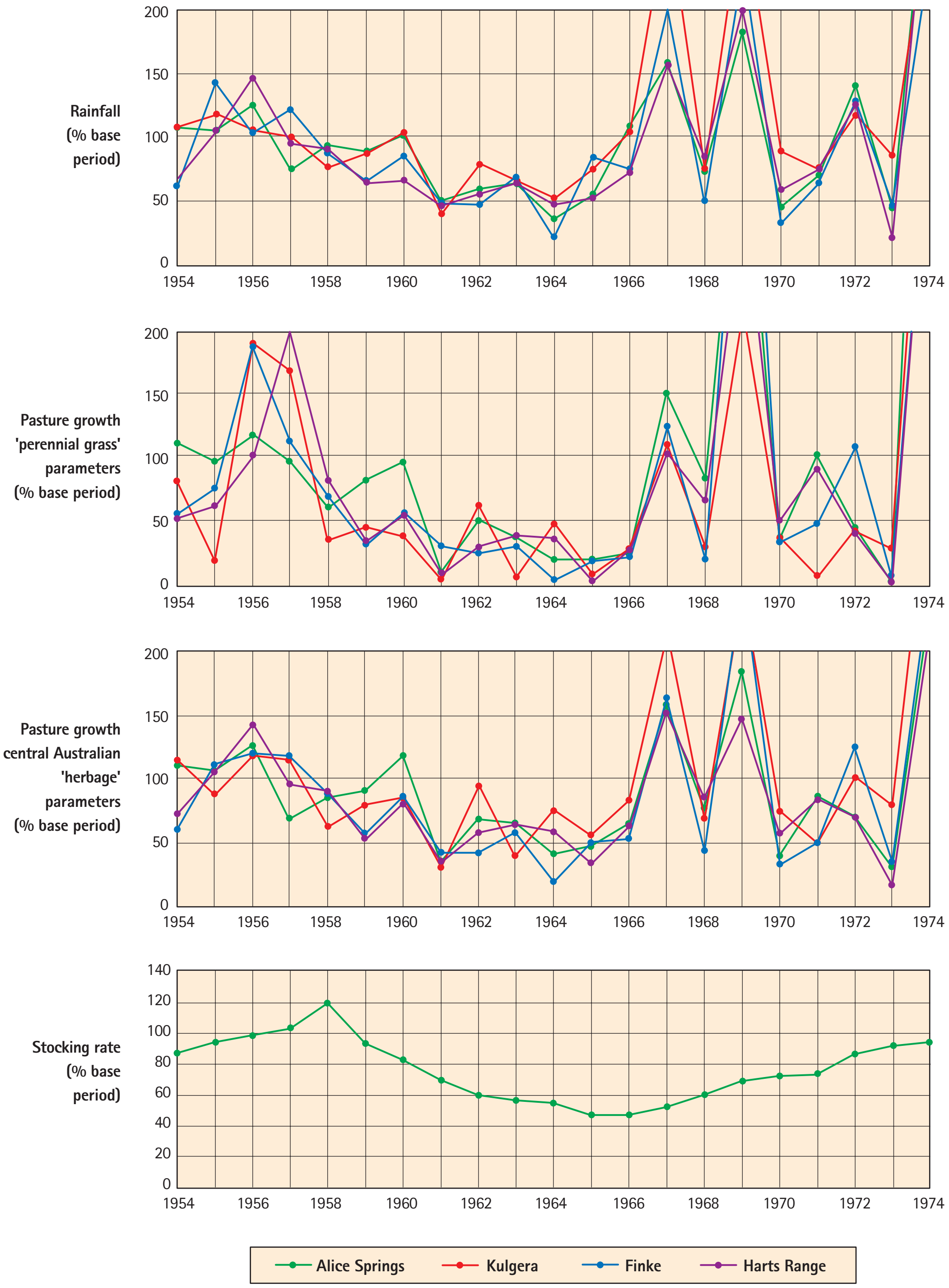


Figure 2.6 Episode 6 for central Australia in the 1960s. Time series of: (a) rainfall; (b) simulated pasture growth using 'perennial grass' parameter set; (c) simulated pasture growth using central Australian 'herbage' parameter set; and (d) reported stock numbers. The annual period is 1 April to 31 March. Data have been plotted with the X-axis being the 'year' at the end of the 12-month period. Data are expressed as a percentage of the mean of the base period 1953/54 to 1957/58. The year 1960/61 has been taken as the first year of the consecutive drought/degradation sequence.

> property (247 steers. 70 cows and calves). Early part of year was very dry and also for November and December but the cattle did well in the winter months.
>
> *Comments 1961:* Astounding that anything lived. Dust storms were common, the worst being on New Year's Eve 1962. Shifted all cattle off station side of run. During the year sunk a bore 14 miles west of Limestone called it Kuraljin. Stocked it in June, by Christmas had about 400 cattle there. Actually we lost very few cattle, perhaps only 50. Mustered in December and trucked steers, bullocks, old cows and mickies and some poor cows. They were sold to a property at Maree, South Australia. During muster got a fair count and would say that there were 900 left after trucking the 300.
>
> *Comments 1962:* The drought broke in January. Soon there was good feed over a lot of the run. Feed in places where there had been none for almost 10 years. The station side was by far the best. Feed remained until the end of the year. Trucked about 80 odd steers all in good condition for £20 clear home. Trucked 75 horses £9 on trucks to Alice Springs and for pet meat. Had a further 25 in hand but could not get trucks.
>
> *Hindsight:* My battle with Lands Department had begun to reduce the stocking rate from 3000. It fell on deaf ears. I was the Manager by this time and we (my father) were bankrupt. The debt was £19000. The best offer the stock agents could get was £16000. We were allowed to stay on no wages. I started to convince my father the horses had to go. Far too destructive.

The good rains of January 1962 appeared to break the drought and highlighted the capacity of the resource to respond following drought (Connellan 1965). The rangeland scientist R. Perry (1962, p. 91) concluded from his field observations in April 1962:

> The widespread and vigorous recovery of the vegetation of central Australia following the recent drought-breaking rains indicates that drought causes little long-term damage. This is to be expected in an arid area where the natural vegetation has evolved under recurrent droughts. The low grazing pressure caused by stock reductions during the long drought combined with the high forage production from palatable annual plants has resulted in a natural deferment of grazing on perennial grasses and top feed. The perennial grasses, at least, are probably in a healthier condition than after a more normal succession of seasons.

However, as Perry could not know, drought conditions were to return in 1963.

Bowman (c. 1980, p. 26) in a history of the Glen Helen property (west of Alice Springs) described how market forces aided the reduction of stock in the drought:

> But other big changes came into being from 1960 on, the one that had most effect on Glen Helen was in the financial field, in 1962 the grand old pastoral firm of Goldsbrough Mort & Co. was taken over by Elder Smith & Co. and became Elders G.M. and a much tougher financial policy came into being. In the middle sixties the Centre was in the grip of one of the worst droughts on record, South Australia and Victoria on the other hand were experiencing good seasons and the trend there was to get out of sheep and into cattle. There was a very strong demand for store cattle in these states and there was a good deal of pressure brought to bear on stations with high level overdrafts to sell their entire herds in this market and this policy did in fact reduce the numbers of cattle in the centre though in spite of the drought they were holding their own in many cases.

J.R. Purvis provided the following comments for the period 1963–65 as the drought continued:

> *Comments 1963:* Trucked 23 horses. 200 cattle. Horses £10 on trucks, cattle £21 clear (of freight). Season was dry – in later part of year cattle started to die. End of horse era. Previously kept to break in to sell for war effort, then races and stockhorses (£10/hd to break in). Shot balance of horses (~200) after sale.
>
> *Comments 1964:* In November sold 20 calves and 50 steers to a property, SA. Then took all the herd (350 cattle) to a bore I had sunk in the spinifex in the south-western corner of run. Cattle were very poor.
>
> *Comments 1965:* In Feb sold 100 steers to a neighbour and 115 bulls (mickey bulls that were too poor to brand and cut) all very poor. This is the worst year of this drought and certainly the worst year since the block was taken

> up about 1918. December brought storms and although much of the country is extremely bad, still some parts of the run are quite good (storms) and cattle are picking up (on Woodgreen). I would say that 2/3 of the entire scrub is dead as a direct result of the last 3 years. The stock have nothing to do with the scrub dying. Almost all the scrub is totally unpalatable. If stock resort to eating mulga they have about 6 weeks to live.
>
> Hindsight: The drought started to break in 1966. We had 288 total cattle left.

The Northern Territory Administration requested that the Soil Conservation Service of New South Wales report on soil erosion and pasture degeneration associated with the drought. Surveys were conducted from September 1965 to April 1967 which included the worst of the drought and the period after the drought had broken with heavy rainfall in January–February 1966 over part of the region and over the whole area in February–March 1967 (Condon *et al.* 1969a).

Because of their previous experience in New South Wales, Condon *et al.* in 1969 (1969b, p. 162) put the drought and degradation episode into an historical context referring to the degradation episodes already described.

> It is most important that the mistakes perpetrated in the early grazing history of arid regions of other States should not be repeated in Central Australia. At the turn of the century the 1901–02 drought reduced the sheep population of the Western Division of New South Wales from 13½ million to 3½ million. Sheep numbers later stabilised at 6-7 million on 125,000 sq miles, reaching 8 million sheep during the current run of good seasons. A similar situation occurred on sheep country in the north-west of Western Australia in the late 1930s. In both cases the excessive stock numbers, carried on fewer watering points than are available today, devastated practically all of the more productive but highly erodible country.
>
> This trend has been repeated on several leases in Central Australia which, in the late 1940s and early 1950s, carried stock far in excess of their capacity even at their present level of development.

Animal numbers had built up from 220,000 in 1947 to peak at 420,000 in 1958. There had been a parallel increase in the number of leases and establishment of sub-artesian bores as permanent watering points (Condon *et al.* 1969a, p. 49):

> Availability of permanent water means, of course, that even during the most severe drought, stock may be retained on country much longer than is good for the country.

One of the team (G.M. Cunningham) believes that rabbits were also a significant agent of degradation during this period. They ringbarked trees and shrubs and were seen in the branches of shrubs eating the bark.

Condon *et al.* (1969a, p. 60) summarised their assessment as follows:

> Widespread erosion, with consequent serious deterioration of pastures and topfeeds, has taken place on most of the more erodible soils in Central Australia. Areas which were formerly moderately or highly productive have been reduced to a very low level of productivity. That erosion has taken place as a result of grazing is shown by the good condition of comparable types of country which has had relatively little, or only moderate, use.

Previous land and vegetation surveys had mapped 'land systems' (Perry *et al.* 1962) providing a 'reference point to the pre-drought condition of the land' (Condon *et al.* 1969a). Condon *et al.* (1969d, p. 314) listed the condition of 88 different land systems mapped by Perry *et al.* (1962):

> The investigations have revealed that there is serious erosion and pasture deterioration on those land systems containing a high proportion of erodible soils. Erosion is accelerating on these areas, and the good seasonal conditions which have prevailed since January, 1966, in most areas, and January, 1967, over the whole area, have not brought about recovery. Rehabilitation of these areas by natural means will be a very slow process. Unless stocking rates on these lands are reduced in accordance with their condition, further erosion, and deterioration of pastures and top-feeds, will occur.

> The investigations have also revealed there are large areas of country still in fair and good condition, and that the actual acreage of land in mediocre or poorer condition is a relatively small proportion of the total. However, the signs of deterioration on country only slightly susceptible to erosion are sufficient to give warning that there is a limit to the amount of abuse that they can take.

Thus, not all land systems were affected by degradation to the same extent. Land systems containing 'alluvial (particularly floodplain) soils showed some of the most severe degradation. These soils are typically duplex or texture contrast, having a thin veneer of coarser material (typically sandy loam) over clay. The sandy veneer is readily dislodged when disturbed (e.g. by grazing/trampling, vehicle tracks and particularly graders), and when vegetation cover is reduced (e.g. by grazing) these soils are highly prone to accelerated erosion by water and wind. Removal of the topsoil layer leaves a hard impermeable clay subsoil exposed – often resulting in a bare scalded surface'. (G. Bastin pers. comm.)

In parallel to Condon *et al.* (1969a), G. Chippendale also carried out resource condition surveys. Bastin *et al.* (1983, p. 152), describing early development of range assessment in central Australia, summarised Chippendale's approach and findings:

> The effect of grazing and drought on pastures was a source of continual debate until long after drought-breaking rains had fallen in late 1965 and early 1966. In an effort to quantify the extent of the problem, a pasture regeneration survey was conducted between March and July of 1966 under the guidance of the Animal Industry Branch botanist, Mr G. Chippendale. He adapted a condition survey score card developed by Parker and Woodhead (1944; cited by Brown 1954) and scored abundance, vigour, and grazing usage of grasses, forbs, and topfeed; type of grazing animals, amount and type of soil erosion, and presence of weeds. Four water points were selected at random on each cattle station and surveyed with two traverses in different directions from each watering point. Condition assessments were made at 0.8, 1.6, 3.2 and 4.8 km from the watering point. Forty-seven stations out of a total of eighty-nine in the Alice Springs pastoral district were surveyed. The survey was significant as the first attempt at a broad scale regional survey which looked at both soil and plant characteristics.

And later (p. 155):

> Chippendale's pasture regeneration survey showed that in 1967, the Alice Springs district was in generally satisfactory condition. Southern stations were only in fair condition with stations in the north-east and north-west of the district in better condition. Soil condition was generally satisfactory but most stations to the south had extensive areas of wind drift erosion while three northern stations had widespread sheet and gully erosion. Six months after the first drought-breaking rains, Chippendale considered that the district had not fully recovered to the conditions prevailing before the 1958 drought (Chippendale, unpublished report; Division of Primary Industry Files 1967).

Condon *et al.* (1969d, p. 318) developed a system of estimating safe carrying capacity as a function of climate, land system, tree density and resource condition:

> A comparison of the assessed safe grazing capacity with the past stocking history of each lease shows that over two–thirds of the leases (excluding those with a very recent stocking history) have been stocked at a reasonable level and that the very high stock numbers in Central Australia in the late 1950's were due to excessive stocking on a minority of the leases. In the early stages of the drought these particular leases were carrying in excess of three times their safe assessed grazing capacity. Most of these leases show widespread serious erosion on the more erodible soil types.

Condon *et al.* (1969d) analysed the historical stocking rates used on 77 leases where stocking had commenced before 1957. For each lease, the upper quartile of stock numbers, i.e. the level exceeded in 25% of years recorded, was calculated. In most cases, the upper quartile value was close to the average of the pre-drought period, i.e. mid to late 1950s. They found that 69% of leases were 'reasonably stocked' (p. 309)

(i.e. upper quartile historical stock numbers did not exceed assessed grazing capacity by more than 20%). In 25% of leases, upper quartile stock numbers were from 20–100% greater than assessed grazing capacity and 6% of leases were stocking at more than double the assessed grazing capacity. Those leases which exceeded assessed grazing capacity by 40% showed 'widespread serious deterioration of pastures and soils on the more erodible types of country. A return to reasonable stocking levels on these leases will be necessary to rehabilitate degenerated areas and preserve the remainder from deterioration' (p. 310).

Condon *et al.* (1969d) further analysed grazing pressure in early drought years by taking into account the expanding area available for grazing with watering point development (50% increase from 1958 to 1963/64). Adjusting for watering point development, Condon *et al.* (1969d, p. 311) calculated that the early drought (1958) maximum of 346,500 cattle was 80% 'in excess of the estimated maximum safe grazing capacity at that time'. Condon *et al.* (1969d) calculated that two–thirds of the leases were reasonably stocked but the remaining one–third (24 leases) was likely to be carrying three times (152,650 cattle) the safe carrying capacity in 1958. Thus, they concluded that 'the very high stock numbers carried during the early phases of the drought were the result of excessive stocking by less than one–third of the lessees' (p. 311) (although they included over 40% of cattle numbers). They also noted that 'serious erosion is widespread on the more erodible soils on the great majority of these 24 leases particularly those showing a long history of excessive stocking' (p. 312).

Although Condon *et al.* (1969d) identified excessive grazing in the early drought period as important, they did not attempt to partition observed degradation in terms of time (p. 312):

> There is no doubt that the widespread serious erosion and associated deterioration of pastures can be attributed both to excessive grazing during the early use of these lands, and also to the very high stock numbers on some leases during the post-war period to 1959.

As a consequence Condon *et al.* (1969d) emphasised the importance of assessing grazing capacity. Thus we regard the papers of Condon *et al.* (1969a, 1969b, 1969c, 1969d) as a watershed in the scientific analysis of grazing capacity. They attempted what Ratcliffe (1970, writing in 1938), had alluded to but believed not possible, that is, the formal arithmetic calculation of safe carrying capacity. The application of the approach to both western New South Wales and central Australia was described in Condon (1968).

Based on comparison with actual property stock numbers with stocking history before 1957, Condon *et al.* (1969c) indicated that the estimate of safe grazing capacity was in agreement with the upper quartile of stock numbers run on the majority (two–thirds, p. 297) of properties in the region. They further emphasised that substantial reductions in stock numbers to 10–20% of normal grazing capacity were required during extended drought periods and provided a worked example of their recommendations through a sequence of years (1958 to 1963). They also commented (p. 296) that their 'rating values used in determining the grazing capacity of land systems' had been 'as liberal as possible' and that they expected future adjustments to be in a 'downward direction'.

Subsequent re-evaluations of the approach indicated that the grazing capacity of the standard land system (Bushy Park) was over-estimated by a factor of two to three (Bastin *et al.* 1983) and hence was likely to result in over-estimates for other land systems. By inference this re-evaluation suggests that over-stocking had been more widespread than indicated by Condon *et al.* (1969c, p. 297). Nevertheless, Bastin *et al.* (1983, p. 163) concluded:

> Although criticisms have been levelled at the standard land system chosen as a means of setting grazing capacities, it was a first approximation which has since been refined and today still forms the basis for establishing individual station grazing capacities.

A key feature of quantitative approaches developed by Condon *et al.* (1969c), and later, following Episode 7, by Johnston *et al.* (1996a, 1996b) and Episode 8 by Scanlan *et al.* (1994) is that they are transparent, and hence at least allow the application of scientific method to the controversial issue of carrying capacity.

Recovery?

The central Australian degradation episode ended with a period of exceptional rainfall, especially 1973 to 1976 associated with La Niña years and *cool* IPO 'index' causing abundant plant growth (Friedel 1981).

Cunningham (1996) was invited back to central Australia by the Centralian Land Management Association to re-survey sites first visited in 1965/66 with a brief to report factual changes. Cunningham (1996, p. 5) observed the following:

> . . . in the Alice Springs area:
>
> - A considerable improvement in soil surface stability has occurred at a majority of sites – 83% of the sites were eroded in 1965-66 while only 18% showed any erosion at the 1993–95 inspections.
> - Pasture cover has greatly improved on the vast majority of sites. There were:
>
>   71 sites recording zero pasture cover in 1965–66, but in 1993–95 only two sites were devoid of pasture cover;
>
>   pasture cover increases were recorded in 1993–95 on 96% of the sites, while 4% of sites showed unchanged levels of pasture cover.
> - The pasture cover at 67% of the sites was dominated by perennial species in 1993–95, while another 28% of sites had a perennial component in the pasture.
> - Current tree regeneration was recorded at 37% of the sites in 1993–95, while current shrub regeneration was recorded at 8% of sites – 16 species of trees and 7 species of shrubs were observed to be regenerating at the time of inspection.
> - Increases in tree cover density between 1965–66 and 1993–95 were recorded at 65% of the sites.
> - Increases in shrub cover density between 1965–66 and 1993–95 were recorded at 83% of the sites.
> - Increases in both tree and shrub cover density between 1965–66 and 1993–95 were recorded at 58% of the sites.

Bowman (*c.* 1980, p. 32) described the impact of the exceptional wet period on vegetation change on his property:

> In 1974 unprecedented rains were experienced throughout the N.T. and this coupled with the fact that since 1966 there hadn't been a really dry year meant that the country changed completely, where formerly there were open plains these now became dense patches of scrub mostly mulga and widgedy bush and in the hill country springs started running where water had never been known to exist even by the oldest Aboriginals. With so much water and scrub to contend with and the rapid deterioration of the labour force it became very difficult to keep the cattle branded up and the country became overrun with scrub bulls and 50% of the herd got completely out of control and likewise mustering cattle for sale became a difficult operation.

A watershed in the changing of grazier attitudes to carrying capacity is described in the first-hand account of J.R. Purvis presented above and in other papers (Purvis 1986, 1988). He described erosion occurring with early stocking in the 1930s and prior to the 1960s drought. He also described how erosion gullies caused areas to be starved of water and the actions he took including earth banks to keep the water out of the gullies, revegetating degraded areas including the use of buffel grass, and reducing the breeding herd from 1000 in the early 1970s to 420 in 1985 (Purvis 1986). From 1977 to 1985 average dressed weight of sale bullocks increased from 318 to 391 kg.

Purvis (1986, p. 113) documented his approach to reclamation:

1. 'time alone would not repair the damage' since areas destocked for 25 years had not recovered;
2. the goal was to 'retain water on ... potentially productive landscapes' rather than lose it in main creek systems or woody weed infested areas; and
3. quick-responding perennial grasses had to be introduced where perennials have been eliminated.

Tothill and Gillies (1992) in their subjective survey of the condition, productivity and sustainability of the pasture lands of northern Australia provided a comprehensive coverage of over 150 pasture communities. In the case of the 14 pasture communities in central Australia, condition assessments were not made because:

> The degree of spatial and temporal variability of both environmental and landscape resources make it difficult to develop adequate assessment, monitoring and interpretation techniques for pasture and landscape condition in the drier rangeland areas. (p. 11)

Tothill and Gillies (1992, p. 21) further summarise:

> It is generally agreed that there has been a considerable improvement in condition since the 1960s, when it was realised that the pasture resources were seriously at risk from the ravages of feral animals such as rabbits, and from an inadequate understanding of range management (Purvis 1986). This study emphasises how, in a region of such great spatial and temporal diversity, the graziers need to develop an understanding of the unique situation for each property in formulating management. This cannot come from regional generalisations, as in the more predictable and more broadly scaled regions of higher rainfall. As individual properties encompass much of this diversity, generalised production strategies are difficult to devise, and resources are difficult to describe and assess meaningfully.

The comments of Tothill and Gillies (1992) touch on the controversial issue of assessing loss of grazing value at catchment or landscape scale in arid lands. Over-utilisation of some areas of the landscape can result in redistribution of water and soil with infiltration and deposition on run-on sites. This may retain the value of water and nutrients within the landscape, provided the density of inedible trees and shrubs does not thicken on depositional/run-on areas. However, since this woody increase usually does occur (G. Bastin pers. comm.), then increased redistribution of water and nutrients inevitably leads to some loss of production and grazing value.

The last word and review

This episode confirmed the importance of major issues in the arid rangelands, such as identifying the impact of watering points on degradation and the difficulty of clearly detecting degradation effects on production in highly variable environments (e.g. Connellan 1965). A major issue apparent in this and previous episodes was the lack of warning provided to governments regarding the emerging resource devastation. With the development of remote sensing using satellite imagery in the 1970s and range monitoring techniques (Bastin *et al.* 1983), the capability to comprehensively assess arid rangeland condition was demonstrated by scientists working in central Australia (e.g. Pickup and Foran 1987, Pickup *et al.* 1994, Pickup 1996). Considerable progress has been made in interpreting spatial and temporal patterns in remotely-sensed data to identify 'grazing gradients' such as trends of increasing cover with increasing distance from watering points (Bastin *et al.* 1993). Apparent trends in cover following well above-average rainfall indicate the extent of 'landscape damage' attributable to grazing (Bastin *et al.* 1993). Further developments have led to: (a) assessment of 'landscape resilience' by comparing the response of vegetation cover to rainfall with what would be expected with little grazing impact; (b) application of these assessments on grazing properties (Bastin *et al.* 1996); and (c) use of these types of techniques in other States to monitor rangeland condition (Northern Territory, Karfs *et al.* 2000; Queensland, Taube 1999; South Australia, Tynan 2000). Thus, remote sensing provides the opportunity to monitor resource condition over large areas in 'near real-time' when degradation is occurring. Used in conjunction with ground-based monitoring, particularly by graziers, (e.g. Tothill and Partridge 1996) remote sensing has the potential to provide advance warnings, allowing government and grazier action to minimise damage.

This episode also stimulated scientific and grazier advances in addressing issues of how to estimate sustainable grazing capacity (Purvis 1986) and simulate stocking rate strategies and herd/flock dynamics (Foran and Stafford Smith 1991). As Condon *et al.* (1969b, p. 162) asserted 'it is most important that the mistakes perpetrated in the early grazing history of arid regions of other States should not be repeated in Central Australia.' Bastin *et al.* (1983, p. 154) recorded in 1979 that graziers and government alike recognised that the build-up of cattle populations during the 1970s posed a 'threat of possible environmental degradation resulting from the onset of drier years'. However, for this region, and Australia's rangelands in general, the concept of carrying capacity (or grazing capacity) and its calculation have remained a source of scientific and public debate lasting from Ratcliffe (1970, writing in 1938) to the present (Condon 1968, Condon *et al.* 1969d, Bastin *et al.* 1983, Scanlan *et al.* 1994, Johnston *et al.* 1996a, 1996b, Hall *et al.* 1998, Tynan 2000, Bartle 2003b).

Tynan (2000, p. 219) in his review of rangeland degradation in South Australia for the 150 years of land settlement challenged the concept of carrying capacity:

> The use of inappropriate ecological models has perpetuated the concept of a carrying capacity and the idea that land has some fixed capacity to carry stock. The introduction of stock maximums in 1939 as a mechanism to limit land degradation has been ineffective and its primary use is linked to land value. It has contributed to management problems and has been applied with little consideration for the biota and vegetation dynamics under grazing.

In support of this view Condon *et al.* (1969b) had previously calculated separate grazing capacities for 'normal' and drought conditions and had recommended substantial reductions in stock numbers in response to drought. Purvis (1986) adopted an alternative conservative view of 'light grazing and six–month rest periods' resulting in turning off (in April 1985) 'our heaviest bullocks ever in a drier-than-average season when the rest of the pastoral industry in the Alice Springs area was near to crisis status' (p. 111). Foran and Stafford Smith (1991) evaluated some of these different stocking strategies ('high-stock', 'average' and 'low-stock') with the herd and property economic model, Herd–Econ, using all possible sequences of climate variability. The 'average' and 'high-stock' strategies resulted in overall higher income. However, in contrast to the 'low-stock' strategy, enterprises based on 'average' and 'high-stock' strategies would not have survived the climatic sequence described in this episode (i.e. the 1956 to 1965 decade). Foran and Stafford Smith (1991, p. 17) further noted that 'in real life the low stock continues to improve its rangeland resource while the high-stock and average strategies' were likely to increase the risk of resource degradation. The 'low-stock' strategy was similar to that described by Purvis (1986) and the 'last word' is left to him (p. 110):

> If you nurture the land, it will sustain you forever; abuse it and it will break you.

What do we learn for preventing land and pasture degradation?

1. The assessment of resource condition in landscapes with great diversity of vegetation, landform, and degradation and recovery processes is extremely complex, requiring individual property knowledge and remote sensing techniques.

2. The areas most severely affected by degradation were those shown by Condon *et al.* (1969d, p. 310) to be most overstocked compared to calculated grazing carrying capacity.

3. Once these areas were severely damaged they were less resilient in terms of soil stability and pasture quality for many years, and perhaps for decades.
4. Even though there has been an improvement in the vegetative cover, there is a potential shrub problem in some areas.
5. The understanding of climate forcings in central Australia is still the topic of research (e.g. White *et al.* 2003). Current research with Global Climate Models is examining to what extent biospheric feedbacks can amplify or dampen the effects of climate forcings, including inter-decadal variability, on rainfall in arid environments such as central Australia and the Sahel in northern Africa (Zeng *et al.* 1999, 2001).
6. Of all the episodes, this one continues to raise current contentious issues: estimating safe carrying capacity; appropriate response to drought; restoration of degraded areas with exotic grasses such as buffel grass; the role of increasing numbers of watering points in reducing or increasing the risk of over-grazing and loss of biodiversity; the separation of climate and management signals in changes in resource condition; the detection of recovery and irreversible degradation; and the sensitivity of elements of the grazing industry to government monitoring. Rangeland science for all its uncertainty, at least provides an alternative and transparent approach to analysing the issues raised by competing ideologies.

2.8 Episode 7: South-western Queensland in the 1960s and 1970s

The widespread drought of 1964 to 1966 severely affected New South Wales and Queensland (Gibbs and Maher 1967). In south-west Queensland the drought contributed to the economic and resource degradation of the mulga lands, which eventually led to the government-supported South-West Strategy involving property reconstruction and assessment of 'safe' livestock carrying capacity (Miles 1990, Johnston *et al.* 1996a). In the 1960s State and Commonwealth agencies were expanding their employment of agricultural scientists and economists and hence extensive quantitative documentation of financial and resource impacts of drought were made (Miller *et al.* 1973, Dawson and Boyland 1974, Childs and Salmon 1978). This expertise provided the scientific and economic basis for grazier-initiated submissions to government (Warrego Graziers Association 1988) leading to the South-West Strategy involving government-supported enterprise restructuring and other economic, social and environmental strategies (Hewitt and Murray 1999). Since the 1960s, the mulga lands have been studied in detail from different perspectives of ecology (Burrows *et al.* 1985, Page 1997), land administration (Williams 1995), degradation surveys (Mills *et al.* 1989), degradation processes (Miles 1993), grazier knowledge (Warrego Graziers Association 1988), integrated analysis of property economic performance, degradation and stocking rate (Passmore 1990, Passmore and Brown 1991), and objective assessment of carrying capacity for individual properties (Johnston 1996). Because the region has been extensively studied it provides a case study of both drought and resource management. Thus we report the findings from many authors in the following anthology.

Climate history

Table 2.8 and Plate 2.9 show the 20–year period from 1949/50 to 1968/69 spanning the extended drought period from 1964/65 to 1967/68. The period 1949/50 to 1956/57 was generally average to well above-average with the exception of the drought year 1951/52. The La Niña years of 1950/51, 1955/56, 1956/57 had average to well above-average rainfall contributing to this favourable rainfall period. The period 1957/58 to 1961/62 was below-average to average including the El Niño year of 1957/58 with extreme rainfall deficiency. Above-average rainfall occurred in 1962/63 and was regarded as a year of excellent pasture growth (Ebersohn 1970, Johnston 1996). The next five years were well below-average and included the two–year drought period of 1964/65 and 1965/66. The two El Niño years 1963/64 and 1965/66 had below-average rainfall and in combination with the 'failed La Niña' year of 1964/65 contributed to the severity of

Table 2.8 Extended drought period (brown) during regional degradation Episode 7 in south-western Queensland. The extended drought periods were calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12-month period (1 April to 31 March). Percentage anomaly was calculated from long term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of –30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, 'El Niño' years were SOI ≤ –5.5, 'La Niña' years were SOI ≥ +5.5). The year 1951/52 has been indicated as an 'El Niño' year based on SST and SOI indicators other than the official SOI. Years in the table are indicated only by the starting year, i.e. 1949 is the period 1 April 1949 to 31 March 1950, referred to in the text as 1949/50.

Episode	Rainfall Anomaly										
Episode 7 South-west Queensland	Year	**1949**	**1950**	**1951**	**1952**	**1953**	**1954**	**1955**	**1956**	**1957**	**1958**
	% Anomaly	+57	+75	-34	+10	+4	+53	+107	+4	-46	-8
	Year	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**
	% Anomaly	-29	-11	0	+36	-19	-45	-39	-17	-20	-2

the drought period. Other ENSO indicators available for 1964 (Wolter and Timlin 1998) indicated a relatively rapid breakdown of the La Niña after October 1964 with the formation of the 1965 El Niño. From a seasonal climate forecasting viewpoint, October 1964 represents a major 'failure' in the sense that an extreme summer drought occurred following a strongly positive SOI in spring.

As indicated in Episodes 5 and 6, the IPO 'index' was very *cool* through the 1950s and was associated with the series of above-average rainfall years of the 1950s and in some cases, in association with La Niña years. The IPO 'index' was only slightly *cool* during the 1960s, but returned to be very *cool* towards the end of the 1960s and early 1970s. Thus, Episode 7 is characterised by generally favourable conditions during the early and mid 1950s, followed by intermittent droughts in the late 1950s, an outstanding year in 1962/63 and then a devastating drought, including two back-to-back severe years 1964/65 and 1965/66.

Data sources and chronology

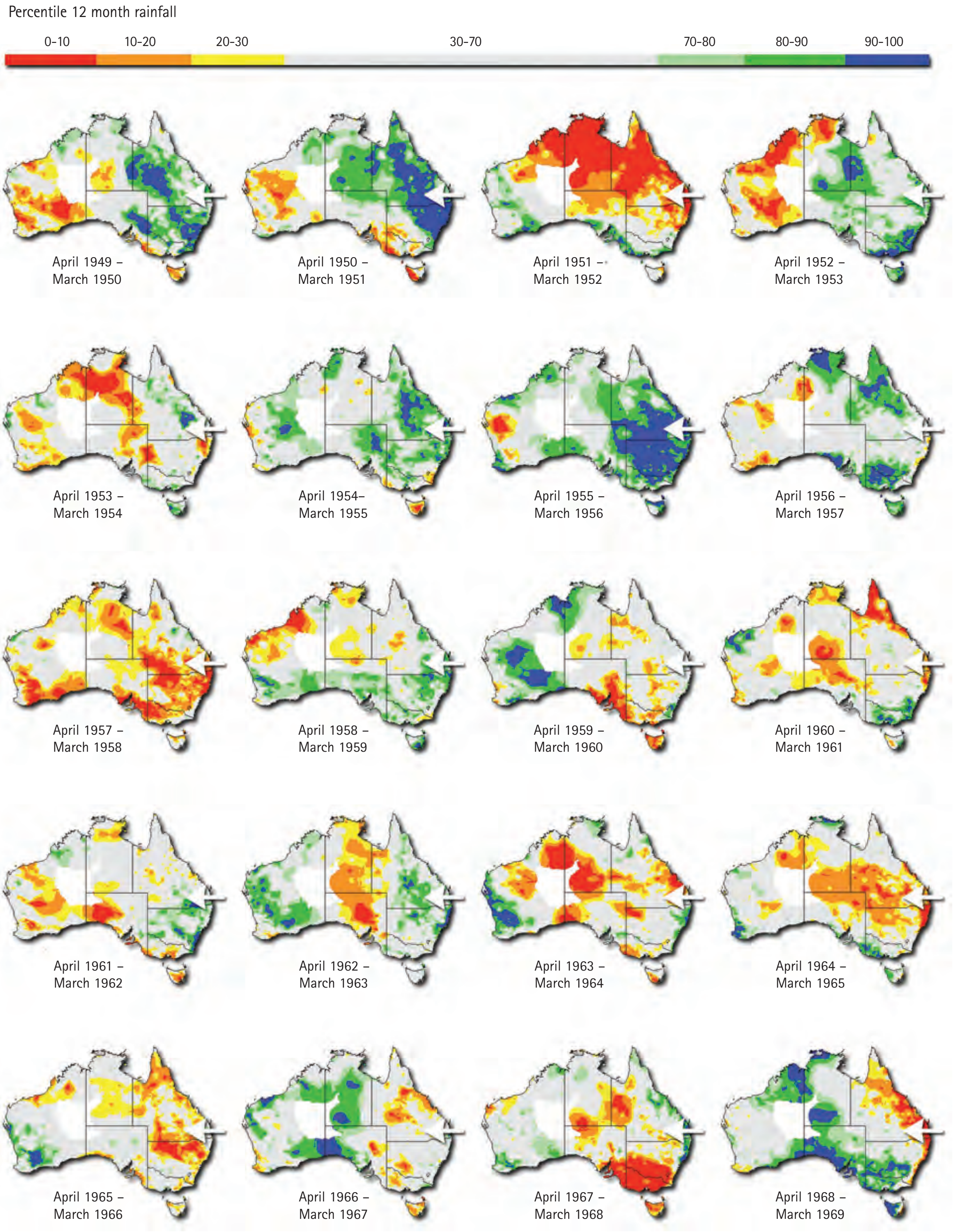
Animal data are from shire statistics reported to ABS on 31 March. Stock numbers have also been generously provided by the owners of a property (G. Stone pers. comm.) regarded as being in fair to good condition (P.W. Johnston pers. comm.). Pasture growth simulations (Figure 2.7) were for 'perennial grass' with model parameters derived from data sets collected near Charleville, south-west Queensland (Johnston 1996, Day *et al.* 1997).

Rainfall, pasture growth and stock numbers for the early and mid 1950s were high compared to the base period taken as April 1959 to March 1963. The base period had intermittent droughts (1957/58 and 1959/60) between reasonable years. Rainfall from April 1963 to March 1966 had years as low as 40% of the previous period. Simulated pasture growth showed a large decrease from 1963/64 to 1964/65 with growth for 1964/65, 1965/66, and 1966/67 being 20–40% of the base period. Reported stock numbers for Quilpie and Murweh did not decline until March 1966, and in March 1967 they were 80% of the previous wetter period. Importantly, stock numbers in Quilpie and Murweh shires actually increased in 1964/65 in the first year of severe drought. Thus the episode is characterised by the retention of high stock numbers even though pasture growth was greatly reduced. As other authors will describe, this is the likely cause of this degradation episode.

Observations and analysis

Detailed documentation of graziers' responses to the drought have been reported by Miller *et al.* (1973) who conducted a farm survey into the effects of the 1964 to 1966 drought in Queensland. They sampled 14 properties in the 'mulga' zone. Stocking rate changes from 1962/63 to 1965/66 were small (3% decline per year) compared to other regions in Queensland (e.g. 9% decline in some areas of 'southern savannah' p. 42).

Episode 7
South-west Queensland 1950-1969



April 1949 – March 1950

April 1950 – March 1951

April 1951 – March 1952

April 1952 – March 1953

April 1953 – March 1954

April 1954– March 1955

April 1955 – March 1956

April 1956 – March 1957

April 1957 – March 1958

April 1958 – March 1959

April 1959 – March 1960

April 1960 – March 1961

April 1961 – March 1962

April 1962 – March 1963

April 1963 – March 1964

April 1964 – March 1965

April 1965 – March 1966

April 1966 – March 1967

April 1967 – March 1968

April 1968 – March 1969

Plate 2.9 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 7. The El Niño years were 1951/52, 1953/54, 1957/58, 1963/64, 1965/66. The La Niña years were 1950/51, 1955/56, 1956/57, 1964/65.

Episode 7 – South-west Queensland 1960s

Time period: 1950 to 1980
Base period: 1959 to 1963

Figure 2.7 Episode 7 for south-west Queensland in the 1960s: time series of (a) rainfall; (b) simulated pasture growth using 'perennial grass' parameter set; and (c) reported stock numbers. Paroo shire rainfall is represented by Eulo rainfall station. The annual period is 1 April to 31 March. Data have been plotted with the X-axis being the 'year' at the end of the 12-month period. Data are expressed as a percentage of the mean of the base period 1958/59 to 1962/63. The year 1964/65 has been taken as the first year of the consecutive drought/degradation sequence.

Miller *et al.* (1973) examined whether high stocking rates before the drought caused severe losses during the drought. Across Queensland they found that stocking rate before drought did not have any effect on the economic outcome of the drought and hence they conducted further analyses on graziers' responses to drought.

Miller *et al.* (1973) examined the economic impact of different drought tactics including selling stock, agisting, and feeding. They noted (p. 41) only two properties out of the total of 188 Queensland properties surveyed 'had any home-grown fodder or grain held as reserves'. Miller *et al.* (1973, p. 43) found that 'a high rate of sales and large positive trends in them were the most successful tactics in all types of enterprise' (i.e. cattle and sheep). 'This finding implies that the best economic tactic for an owner, beset by drought, is to increase his rate of sales early in the drought and to continue to increase it at fairly frequent intervals if relieving rains have not fallen'. They added the qualification that the capacity to recover stock numbers by purchase after drought should be maintained.

Reductions of stock through sales for the mulga properties (i.e. south-west Queensland) surveyed were low (average 11%) compared to 14–20% for other sheep regions of Queensland. For the mulga properties, there was no increase in sales as the drought progressed. Only one of the 14 properties used agistment, the others relying on drought feeding (57%) or doing 'neither' (43%). All properties used scrub feeding. Miller *et al.* (1973, p. 45) stated:

> The value of the cut scrub in terms of starch equivalents could not be quantified, since it was a function of many variables, such as type, size and density, method of cutting, time spent preparing the scrub for the stock, energy applied to the task, and method used. Most owners used chain saws, but others used bulldozers, tractors, or even axes for the purpose. The magnitude of the task can be gauged from the times of 6–10 hours daily for 5–7 days a week, which were cited most commonly.

Miller *et al.* (1973, p. 45) compared reported livestock death rates for scrub feeding with other feeding strategies:

> ...the mean death rate of two seasons of drought revealed that the deaths were at a significantly higher level during periods of scrub feeding than when other tactics were employed. In some cases, of course, this might have been due to the fact that the animals were in extremis before scrub feeding was used as a final desperate tactic:

Miller *et al.* (1973, p. 81) were unable to quantify the economic value of scrub feeding but expressed concern regarding this as a drought tactic:

> While animals were being fed purchased feed, they were also getting additional feed in the form of cut scrub. We have already pointed out that the amount of feed they received in this way could not be quantified, but certainly death rates rose substantially during periods in which scrub was fed to stock. This does not mean necessarily that scrub is intrinsically harmful. It may well be that the amount of scrub made available was not adequate, either alone or in association with purchased feeds, to support life. Possibly many of the animals receiving scrub as feed were dying anyway. Because scrub feeding could not be assessed quantitatively, we could not relate it to either our Income Index or our Replacement Capacity, since its effects were merged with those of hand feeding.
>
> There is, however, one aspect of the tactic to which we feel attention should be drawn, even though it lies outside our terms of reference. A number of owners in different zones reported that they used scrub feed until all of it or at least more than half had been consumed. Since, in many districts, this type of vegetation not only provides a source of animal food but also stabilises the soil, it would seem to be important to instigate a long-term study into the responses of the different indigenous scrub species to such intensive use, and their subsequent recovery. The results of such a study could well be important in determining management policy during droughts.

Miller *et al.* (1973, p. 83) concluded that their survey showed that early selling produced the best economic outcome:

> It appears from our results that, under the circumstances existing during the 1964-66 drought, the best policy was to increase the rate of sales early in the drought and then go on increasing it at fairly short intervals until adequate rain had fallen. Three objections are commonly raised against such a policy. The first is that the Replacement Capacity will be reduced at the end of a drought to a level that might prejudice the future recovery of the flock or herd, unless it is increased post-drought by purchase of animals from outside sources. The second is that the prices for animals after a drought will rise and the owner who sold at ruling in-drought prices will be forced to buy at enhanced post-drought ones. The third is that the excessive purchase of animals from outside sources may so change the environmental adaptability in a flock or herd that its economic productivity may be decreased.
>
> Since we found no evidence that a high level of sales did, in fact, depress the Replacement Capacity, we can only state that from our results over the time span of the survey it made no difference whether a man fed, used agistment, or sold: he had the same problems of replacement, except that the man who sold might have more money in the bank – both from his sales and from the savings resulting from reduced levels of feeding or agistment.

Degradation assessment

The extent of degradation was comprehensively evaluated in a series of land surveys. Miles (1990, p. 77) in a situation report for the region stated:

> In the disastrous 1964-66 drought, graziers in western Queensland called for an investigation into the economic plight of their industry. The producers of the south west were managing a drought when faced with high accumulated debts, interest charges and low commodity prices.
>
> This investigation included a full physical survey of the region (Western Arid Land Use Survey, 1974). The survey covered over 60 million hectares and took over 15 years to complete. The results showed that while most of the area was still in a stable productive state, degradation was evident. The area most severely affected was the mulga lands. The mulga lands comprise the shallow infertile red earths with the mulga tree *(Acacia aneura)* the dominant tree species. Within this area extensive sheet erosion and woody weed invasion [were] evident.
>
> The results of this survey prompted further research into the problem and in 1985 a joint investigation into the degradation by the Queensland Department of Lands and the Queensland Department of Primary Industries was conducted (Mills *et al.* 1989). The results of the survey indicated that in the mulga lands west of the Warrego River:
>
> - 44% of the area had substantial woody weed problem;
> - 79% was suffering from over-utilisation of mulga;
> - 64% of the properties in the area had 60% of their land grazed bare, thus predisposing this land to erosion and high rates of runoff; and
> - 45% of the properties were suffering from substantial sheet erosion with a further 16% displaying minor symptoms of erosion.
>
> In summary, over two thirds of the area was degrading. Thirty percent of the area was eroded and twenty percent of the area had greater than 5,000 turkey bushes per hectare.

In 1988 the Warrego Graziers Association made a submission to the United Graziers Association on the degradation of south-west Queensland recommending government action on property aggregation, review of stocking rates, control of native and feral herbivores and reclamation of degraded country. They reviewed the processes of degradation (p. 4):

> With the closer settlement blocks and improved watering, stock were retained during dry times and effective use was made of top feed. The increased utilisation led to an overall and consistent reduction in biomass. Fires were reduced from relatively infrequent events to a point where fire was an unlikely occurrence. The 'fire sensitive plants' such as the *Acacia, Dodonaea* and *Eremophila* shrub species, expanded. The decrease in competition from the more palatable perennial grasses aided substantial establishment of these less desirable species. The intense and prolonged grazing of the perennial grasses during droughts and recovery phases led to a decline in their recruitment and reproductive success.
>
> Rainfall in the area is unreliable and unpredictable, consequently the opportunities for perennial seedling establishment are infrequent. Although trees, shrubs and grasses draw nutrients and moisture from predominantly different levels, the overlap of these zones implies considerable and continual competition for resources. The massive red earths when devoid of vegetation rapidly collapse, resulting in surface sealing, reduced infiltration and increased susceptibility to erosion. These complex phenomena present an association of factors which have resulted in reduced productivity and substantial degradation to the region. Stocking rates are further confounded by the economies of size in the region, with many blocks offering less than desirable incomes for the capital invested. Rated carrying capacities and declared living areas appear to be no longer appropriate.

The Warrego Graziers Association (1988) presented evidence on Paroo River Catchment behaviour supporting increased degradation of the Catchment. The number of flows in the Paroo River had increased since the 1960s without increases in rainfall suggesting reduced ground cover and increased runoff. They stated (p. 12) that 'a major biological shift' had occurred in the 1950s and that woody weeds were regarded as 'becoming a problem in the early 1960s'. Monitoring of woody weed commenced after 1965 on transects across properties and indicated substantial increases of several woody weed species (Burrows *et al*. 1985).

Role of climate variability in degradation of mulga lands

Mills (c. 1983, p. 8) asserted in his interim report of 'Land degradation in the Arid Zone of Queensland':

> According to Condon *et al.* [1969a] and Dawson [1974] the prime cause of land degradation is the maintenance of excessive grazing pressure on sensitive types of country during drought periods. Management during drought periods is therefore of over-riding importance in preventing the onset of land degradation on sensitive land types. It follows that a drought assistance policy which creates an incentive for graziers to reduce grazing pressure during the early stages of drought is a high priority.

Page (1997) provided a conceptual model for understanding the interaction of climate variability that leads to soil erosion and woody weeds. The combination of drought and high stock numbers results in the accelerated death of perennial grasses (Dawson and Boyland 1974, Hodgkinson and Cook 1995). The extended drought and presence of stock supported by mulga resulted in virtually bare ground (W.H. Burrows pers. comm.) and very low grass basal area. Thus, soil erosion was likely to be due to high winds and increased runoff (Miles 1993) resulting from reduced infiltration capacity. In the soils of the mulga lands, nutrients (i.e. nitrogen, phosphorus) occur mainly at the soil surface and hence the loss of several centimetres of surface soil is sufficient to greatly reduce potential plant production (Miles 1993). Increased runoff causes seed losses from the runoff area (Page 1997). Reduced grass production reduces the potential for fire and increasing density of woody species results in greater competition for water and nutrition.

The effect of historical climate variability in driving the degradation processes (soil erosion, woody weed infestation) is uncertain. W.H. Burrows and A.J. Pressland (pers. comm.) stated that these degradation processes were apparent since the turn of the century (i.e. 1900s), as described in Episode 1. A.J. Pressland identified severely degraded sites in the 1970s that were attributed to a combination of drought, high stock numbers and mulga feeding in the 1890s–1900s. Similarly woody weeds had already been identified as a problem in the early 1960s as part of a continual degradation process since the 1890s (W.H. Burrows pers. comm.), and perhaps even earlier (1870s–1880s, R. W. Condon pers. comm.).

The Humeburn transect (Burrows *et al.* 1985) established in the mid 1960s shows increasing trends in woody weed densities for false sandalwood (*Eremophila mitchellii*) and grey turkeybush (*Eremophila browmanii*) from 1965 to 1979. Hopbush (*Dodonaea adenophora*) declined from 1965 to 1972 then substantially increased to 1979. Green turkey bush (*Eremophila gilesii*) increased from 1965 to 1972 then declined (Mills 1983). R. Miles (pers. comm.) thought that the reduction in summer rainfall relative to winter rainfall aided the recruitment of the turkey bush in the absence of competition from grasses. A.J. Pressland (pers. comm.) stated that for the Momanby exclosures (used by Beale 1973), turkey bush was 'only mentioned in dispatches' in the 1960s but had increased substantially by 1979/80. Similarly Witt and Beeton (1995) found, from the examination of aerial photography, that the major increase in woody cover (including *Acacia* spp. and other woody species *Eremophila* spp., *Dodonaea* spp.) occurred between 1969 and 1981 on hard mulga, dissected residuals and sand plain mulga land systems. They listed as possible causes the absence of fire, and the favourable establishment conditions due to high rainfall between 1973 and 1977. Burrows (1986) noted that woody plants are at an advantage (over grasses) on infertile sites because of their better intrinsic and extrinsic cycling of scarce nutrients and the fact that they (usually) do not have to re-establish after drought.

Importance of the drought period in degradation processes

The drought period 1965/66 (Miller *et al.* 1973) involved heavy grazing pressure of grasses and the conditions for severe soil erosion and woody weed establishment at the break of the drought. Simulations of pasture growth, actual drought declarations (1964 to 1973) and impact on financial income (1967 to 1970) (Childs and Salmon 1978, Mills *c.*1983) suggest that the effects lasted longer than just the two years of drought and could have accelerated the processes of degradation.

The submission of the Warrego Graziers Association (1988, pp. 14–15) summarises the processes resulting in an extension of the drought period despite apparent relief rain in some regions.

> Some vegetation communities such as the rolling downs are more resilient and have persisted under the system. Others such as the Mulga Lands are fragile and have proceeded to decline more rapidly. The saving factor for areas such as the Downs of central Queensland and other areas such as the Channel country is that during the pulse and decline of seasons when grass becomes limited, stock have to be removed. In dry times in the mulga areas, stock are fed trees and stock numbers are retained during drought. The ability to maintain stock numbers during dry times by the use of mulga top feed leads to the situation where stock numbers are high during that crucial post drought period. At this time grasses are struggling to recover and set seed for the next dry period. This constant grazing has led to selection pressure on favoured perennial grasses resulting in a radical decline in soil seed stores and recruitment.
>
> The pressure on grasses through grazing in the post drought periods has led to very little opportunity for the grasses to expand and provide adequate ground cover in good seasons. This has resulted in the large expanses of bare areas previously described. These large bare areas offer little resistance to rain drop impact, erosion and runoff. The increase in runoff results in a serious loss of an extremely limited resource placing the area in an artificial drought situation.

The economics of destocking

A major issue in this episode is the extent to which the retention of stock, supported by scrub feeding and availability of mulga during 1965/66, accelerated the degradation process as described above. Miller *et al.* (1973) suggest that this grazing management tactic may not have been the best financial alternative and may not have even reduced stock deaths relative to other areas of Queensland, nor improved 'the replacement capacity' (Mills *c.*1983).

Thus both the Miller *et al.* (1973) analysis and Mills' assertion would suggest that financial and resource benefits would have resulted from reduced stocking in the 1965/66 drought. We report here reviews derived from several surveys of different properties.

Rose (1998) reviewed the economics of stocking strategies in south-west Queensland. Comparison of animal productivity for a property which had reduced stock numbers by 30% (from 0.64 to 0.44 sheep/ha) showed a 3% increase in wool production per ha, and a 30% increase in lambing and weaning rates.

Rose (1998, p. 14) also summarised the property surveys of Childs (1973a, 1973b, 1973c) conducted in the late 1960s after the onset of the severe 1965/66 drought:

> Childs [1973a,b,c] surveyed over three years, 1967-68 to 1969-70, soft and hard mulga country south west of Charleville and black soil country, around Tambo, Augathella and Cunnamulla. The aim of the survey was to measure managerial performance and determine why different managers perform better at a property level. During the survey period, the area was moving into drought. Four financial situations emerged in which producers could be grouped.
>
> 1. Producers who maintained income over the three year period whilst going into drought, did so by *maintaining production (lamb marking, wool cuts and low mortalities)* [Rose's italics]. The producers reduced stock numbers to a level which maintained the per head production performance of the flock/herd during the dry period. Income consisted of sheep and cattle sales, especially within the first year and production levels similar to the pre drought period.
>
> 2. The second group of producers had their returns increase in the second year and decrease in the third year. They reduced stock numbers but not early enough to maintain production performance (stock were not in as good condition as the first situation).
>
> 3. [In] the third financial situation, producers decreased returns in the second year and had constant returns in the third year. These producers did not reduce stock numbers in time thus production performance decreased. In the third year, production and income remained constant.
>
> 4. In the final situation, producers decreased returns in the second and third years. These producers did not reduce stock numbers, whilst moving into a drought. Costs increased through feeding, and production reduced. In the third year, stock numbers were reduced but as stock were in poor condition, production was reduced and feeding costs had increased.

Recovery?

Whilst stock numbers increased during the subsequent above-average rainfall period of 1973/74 to 1977/78, numbers declined rapidly with a return to below-average years from 1979/80 to 1982/3 with the lowest stock numbers for the 40–year period reported in March 1984. Rainfall records, mortalities, simulation of non-degraded pasture growth and stock-to-growth ratio do not indicate that this drought period (1979 to 1983) was substantially worse than the previous period. Nevertheless, the length of drought declaration, November 1979 to mid 1983, and the larger decline in animal numbers suggest several, as yet unresolved, hypotheses:

1. Degradation that occurred during the 1960s resulted in a damaged resource in terms of reduced grass basal area, established competitive woody weeds and mulga, poor soil infiltration characteristics, and reduced available soil nutrients. All these factors would result in greatly reduced pasture growth in below-average rainfall years, and hence, greater likelihood of feed deficits, bare ground and dust storms (Figure 1.8).

2. Because of the lessons learnt in the 1960s, especially the high mortalities, graziers showed greater responsiveness to the onset of drought conditions by reducing stock numbers.

3. Stock numbers were reduced rapidly because the capacity to drought feed using mulga was no longer available, the quantity and quality of this natural 'fodder store' having not yet been replenished. This is the least plausible hypothesis as graziers would be expected to have conserved mulga and these areas not used in the 1960s were likely to be available in 1979 to 1984.

In conclusion, many of the processes of degradation had been initiated as early as first settlement and were revealed in subsequent droughts (Warrego Graziers Association 1988). The closer settlement of the 1950s resulted in properties too small for viable enterprises and stock numbers were too high. Because of the economic decline in wool enterprises, graziers with small flocks were unlikely to feel that substantial destocking was a viable option (J. Childs pers. comm.). Stock numbers were not substantially reduced in the severe drought of 1964 to 1966 with scrub feeding used in an attempt to keep animals alive. Thus, there was great grazing pressure on fragile soils and perennial grasses both during the drought and in the following period. The processes of woody weed expansion and soil erosion appear to have been accelerated and continued through the 1970s and 1980s. The documentation of the extent of the problem in the 1980s led to a grazier-supported initiative to promote property amalgamation, control grazing pressure and objectively assess safe carrying capacities (Johnston *et al.* 1996a, 1996b). The subsequent impact on management and resource condition is still a subject of debate (e.g. Rose 1998).

The last word

W.H. (Bill) Burrows, now an eminent woodland ecologist in Queensland DPI&F, was a young scientist at Charleville at the time of this episode. He has generously provided this recollection:

> Dust, gorgeous orange-red sunsets, horrendous bull-dust generated by stock trucks on unsealed roads - the dust penetrated everywhere and everything like a perennial 'dry' fog. Dead, decaying 'roos lined every road and track – more tucker than our raptors, crows, wild dogs and foxes could ever dream about - animal guideposts without reflectors. Countless flies! Emaciated sheep and cattle attracted by the pied piper sounds of chainsaws revving, wheeled tractors with end-loaders 'cocked' and ready, D2, D4 and Track Marshall 'dozers with blades raised in salute, Bren gun carriers adorned with logs as tree rammers — all clanking and screeching in the dust as they felled, pushed and pulled the mulga trees down — and the stock survived another day. 'Mulga here, mulga there, mulga, mulga everywhere - good old mulga always saves ya'.
>
> The dull, limp foliage of the trees and shrubs. The old box trees had seen it all before — they dropped their leaves in fright, but with cunning survival instinct. There was no grass to be easily seen, except *Aristida* tussocks here and there. All the river frontages were bare and sealed, the soil surface polished by the wind. The 'Ward Plain', a legendary Mitchell grass reserve 10 miles north-west of Charleville on the Adavale road was lifeless — except for the constant meanderings of townsfolk's horses, desperately looking for tucker. Further west it was just the same. The 'Warbreckan' blocks north-west of Windorah had been recently balloted. The winners would have felt sure they had won life's lottery. These were the famous 'ashy downs' — the pinnacle of Mitchell grasslands. But by spring '65 there was nary a Mitchell grass stalk for mile upon mile. Walking on those downs even the lightest man or beast left deep indentations in the loose soil - a forerunner of Neil Armstrong's footprints on the moon.
>
> But there was some green about. Every open bore drain had its bowling green of couch grass stabilising its banks, while providing certitude and sustenance to countless sheep and marsupials. And there was the deadly green allure of Ellangowan poison bush on the Eulo-Hungerford stock route attracting hundreds of starving droving stock to their death as they 'hit' it in their unending trek for fodder.
>
> In the Channel country north-westerly dust storms were probably more blinding than those from the traditional south-west. On one trip to this area in November '65 we couldn't drive the Holden ute more than a mile without the radiator boiling at 10 am. Yet that same November I saw the most remarkable sight. Mud fat cattle grazing amongst the stones of Sturt's stony desert just outside of Beetoota. Each small stone was an effective 'mulch' that retained any remaining moisture beneath it and so provided a haven for small 'herbage' plants which the stock sought out. More remarkable still in this time of emaciation, appalling drought and stock death I saw over 1000 of the biggest, fattest Shorthorn bullocks I have ever seen, before or since, grazing the last of the herbage on the dried out bed of Lake Yamma Yamma — the overflow of Cooper's Creek on Tanbar Station. I never did find out the date of the last flood that filled that overflow. But these stock images indelibly printed on my mind that if you correctly matched animal numbers to the feed available there need be no such word as drought in our vernacular. It must have been a piece of cake managing this land before the Europeans arrived.

> And when the rains inevitably returned the miracle of Mitchell grass was there on the Ward Plain and the ashy downs for all to marvel at. How does it do that? Gaia's version of the resurrection. The most beautiful 'pristine' grassland one could ever wish to see born again! But the grasses of the hard mulga lands never really came back. Mulga, friend and foe, had provided sustenance for our stock one time too many. We did not adjust the stock to the grass feed available. We cheated on the grass (as we would repeat elsewhere in the future with urea-molasses supplements) — and in the struggle for growing space the trees and shrubs had finally won.

What do we learn for preventing land and pasture degradation?

1. Episode 7 is the best documented of all the episodes in terms of the different perspectives that are available (e.g. graziers, ecologists, land resource surveyors and economists). It has resulted in the combination of the experiences of graziers and scientists (Johnston *et al.* 2000) to formulate a quantitative approach to the issue of assessing property carrying capacity. Thus the work of P. Johnston and his grazier and scientist colleagues put into practice that which F. Ratcliffe speculated on in Episode 2, and R. Condon initiated in Episode 6.

2. We also draw from Episode 7 the contrasting views that: (a) forecasting of the severity of droughts such as 1964–66 period has a potential role in minimising land and pasture degradation if the appropriate reductions in stock numbers were made; but (b) existing SOI-based forecasting systems would have failed to provide warning of impending drought at the start of the episode (spring 1964). The subsequent rapid development of the 1965 El Niño would have at least provided warning that the drought was likely to continue. We recognise that chaotic processes in the climate system limit the potential reliability of climate forecasting. Nevertheless spring 1964 remains a major outlier in most ENSO-based systems and hence it is worthy of further climatic analysis given the impact on the natural resource described in Episode 7.

2.9 Episode 8: North-eastern Queensland in the 1980s

Episode 8 is a major degradation episode in the high summer rainfall zone of the tropical rangelands. Research from the 1960s onwards concentrated on solving the nutritional and health limitations for cattle production in this environment, especially during the normally dry winter period when pastures are of low nutritional value. These limitations had placed a ceiling on the use of the natural grazing resource. Once these constraints were lifted, by adoption of better breeds of cattle and use of supplements in the 1960s and 1970s, and accelerated by market fluctuations, the problems resulting from increased utilisation quickly became apparent (Gardener *et al.* 1990). Once initiated, degradation processes in the tropics (i.e. loss of soil and perennial grasses) can prove difficult to stop (Mott *et al.* 1981) unless there is a drastic change in stock management (Landsberg *et al.* 1998, Ash *et al.* 2002). High rainfall (average of 500 mm in the five months of summer) drives the degradation processes of exotic weed invasion and soil erosion with substantial downstream effects to the Great Barrier Reef lagoon (Anon. 1999).

Climate history

Table 2.9 and Plate 2.10 show the 20–year history from 1969/70 to 1988/89. The period from 1970/71 to 1981/82 had mostly average or above-average years with intermittent droughts in 1969/70, 1972/73, 1977/78 and 1979/80. The El Niño years of 1969/70, 1972/73, 1977/78 had below-average rainfall (–20% to –28%). The extended drought period was more severe than indicated by 12–month rainfall in Table 2.9. When only summer rainfall (November–March) was considered the consecutive four years (1984/85 to 1987/88) were each ranked in the lowest 33% of historical years. The percentage anomaly in summer rainfall for these years was –45%, –24%, –47% and –41%, respectively. Thus the consecutive four–year period resulted in very unfavourable conditions for summer pasture growth. During this period above-average winter rainfall occurred (1985 and 1986) allowing animals to be retained despite the lack of summer growth. In fact the

Table 2.9 Extended drought period (brown) during regional degradation Episode 8 in north-eastern Queensland. The extended drought period was calculated using regional rainfall (Figure 1.1, Plate 1.2) for a standard 12–month period (1 April to 31 March). Percentage anomaly was calculated from long-term mean annual rainfall. The first year of the extended drought period was the first year in which rainfall was less than 70% of the mean (i.e. an anomaly of −30%). The drought was considered broken when average (>95% of mean) to well above-average rainfall occurred. 'El Niño' (red) and 'La Niña' (blue) years were classified as described in Chapter 1.2.1 (i.e. for June to November SOI, 'El Niño' years were SOI ≤ −5.5, 'La Niña' years were SOI ≥ +5.5). Years in the table are indicated only by the starting year, i.e. 1969 is the period 1 April 1969 to 31 March 1970, referred to in the text as 1969/70.

Episode	Rainfall Anomaly										
Episode 8 Dalrymple Queensland	Year	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**
	% Anomaly	-28	+11	+61	-20	+119	+16	+35	-3	-27	+45
	Year	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**
	% Anomaly	-19	+27	+4	-57	+43	-37	-4	-27	-39	+2

substantial rainfall during the dry seasons was thought to have greatly contributed to animal production during these years (J. McIvor pers. comm.).

There has been a strong correlation between SOI and rainfall in this region (McKeon *et al.* 1990). For example the El Niño years of the 1980s (1982/83, 1987/88) had severe rainfall deficiency (−57% and −39% respectively) and similarly the subsequent extended negative SOI period (1991 to 1994) also had low rainfall (Figure 1.1c).

The IPO 'index' was very *cool* from the late 1960s through to 1977 becoming very *warm* during the 1980s. Mantua and Hare (2002) indicated that the year 1977 was a switch from a *cool* to a *warm* phase in the PDO. Thus, based on the previous interaction between the IPO/PDO and ENSO, drier conditions would be expected to occur after 1977.

Data sources and chronology

Animal numbers are for Dalrymple shire and from the property 'Trafalgar' (Landsberg *et al.* 1998). The accuracy of the Australian Bureau of Statistics cattle numbers for Dalrymple has been questioned (Mortiss 1995, p. 23) as they rely on people accurately completing census/survey forms. 'Evidence gathered by members of the Dalrymple Landcare group and DPI stock inspectors suggests that beef cattle numbers have fluctuated far more than the ABS figures suggest.' Estimates of peak numbers in the mid 1970s are quite different (ABS, 600,000; Mortiss 1995, 1,050,000).

Pasture growth simulations were based on parameter sets derived from a grazing trial in the region (Kangaroo Hills, Gillard 1979). The parameters have been modified to produce a more general set using regional experience (A. Ash, pers. comm.). The simulation of pasture growth includes the effects of conservative utilisation and climate (Figure 2.8) on grass basal cover and confirms the low growth of the mid 1980s and early 1990s.

Observations and analysis

Technological changes causing change in grazing pressure

Major technological changes have occurred in the Queensland cattle industry since the early 1960s. British breeds had been used since first settlement but suffered losses in droughts with 20% breeder mortality and 80% reductions in branding reported (Landsberg *et al.* 1998). In the 1960s there was a major shift to Brahman bloodlines and the introduction of molasses–urea supplementation to increase productivity and reduce deaths. The new practices resulted in a doubling of stock numbers over 20 years, from mid 1950s to the mid 1970s (Mortiss 1995, p. 22-3):

> In 1956 stocking rates were 4.5 beasts per square kilometre, 5.7 [beasts] per square kilometre between 1965 and 1969, 9.6 to 12.3 per square kilometre in 1970, 11.6 beasts per square kilometre in 1974, and 9.1 beasts per square kilometre in 1976 (Frank 1988). The shire numbers peaked at 600,000 in 1977/78 (ABS).
>
> There was little evidence of an overall improvement in the herd performance indicators such as percent turnoff, branding and mortality (Frank 1988). In recent years there is good anecdotal evidence that mortalities have declined through better supplementary feeding, disease control and transportation. Much of the increase in cattle numbers can be attributed to utilisation of new areas of land, with investment in both fencing and watering facilities, brahman infusion, and the use of non-protein nitrogen supplements. The market slump in the mid 1970's resulted in reduced turnoff of all cattle. Good seasons during the 1970's facilitated this increase in numbers as graziers were reluctant to sell cattle at low prices. Dry conditions and better prices encouraged disposal of stock in the 1980's.

Mortiss (1995) further commented that estimates of cattle numbers gathered by the Dalrymple Landcare group and DPI stock inspectors had suggested that beef cattle numbers had peaked at over a million head for the shire.

At Trafalgar, Landsberg *et al.* (1998, p. 109) experimented with supplementary feeding:

> The initial feeding program began in early June [1987] and numbers of cattle were added as the months progressed, until by the end of the year all cattle were included. The program finished when relief rains came in January 1988, and at this time about $75 per head had been invested. However, with no follow up rain, lack of pasture yield resulted in a forced sale of 60% of the herd, leaving about 1600 head. The exercise must be deemed a failure for two reasons: (a) the investment became a loss, and (b) further land degradation occurred.

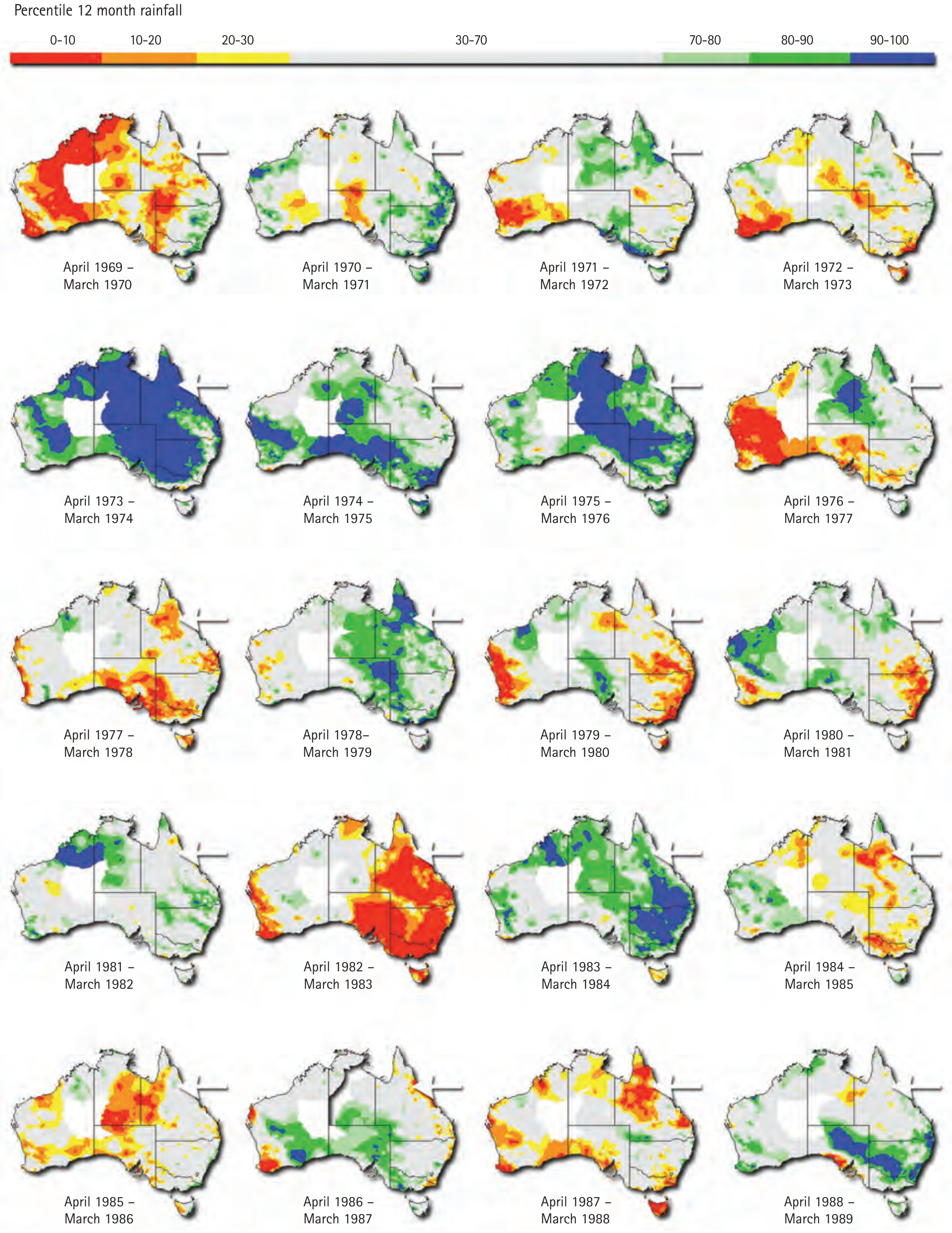
Evidence of soil erosion

The overall effect of all these factors was increased grazing pressure in both wet and dry seasons, resulting in reduced ground cover (Plate 2.11), increased utilisation of 'desirable' perennial grasses, and reduced frequency of burning. The degrading processes that resulted were accelerated soil erosion, pasture composition decline, woody weed expansion (exotics and native), woodland thickening and salinity (Mortiss 1995). Warnings about resource degradation had been provided as early as during the 1965 and 1969 droughts (D. Carrigan pers. comm.). Various studies were conducted during the late 1970s and early 1980s. A.J. Pressland and E.J. Turner reviewed these reports in 1983. We provide a substantial quote here from this Queensland Department of Primary Industries internal report (Pressland and Turner 1983) as it indicates the depth of knowledge that was available prior to the major drought episode (1984/85 to 1987/88):

> As of March 31 1981, 536 400 head of cattle were depastured on 271 holdings within the Dalrymple Shire, the local government authority which controls a large proportion of the Upper Burdekin catchment. Stock numbers had remained reasonably constant in Dalrymple Shire between 1945 and 1964, but between then and 1979, numbers increased from 308 000 to 596 000. The increase in cattle may have been due to a number of factors including change in markets, use of fodder supplements, the spread of cultivation and an increase in the area sown to *Stylosanthes* spp. (e.g. Townsville Stylo). Peter Lloyd (Agriculture Branch, DPI) has data which suggest that the latter factor is highly correlated with stock numbers, and that the decrease in numbers since 1979 can be related to the debilitating effect of Anthracnose disease in Townsville Stylo after 1978. Be that as it may, there has been a consistent increase in pressure on the pasture of this area, and this is now reflected in the condition of both the landscape and pasture.
>
> The report of the Burdekin Project Committee (B.P.C. 1976) indicates that an average of 12.4% of the Upper catchment area (equivalent to 7000 km^2) suffers from soil erosion. This average hides the real figures, though: for example, in the Camel Creek area, 46% of the landscape was considered to have an erosion problem, as was 33% of the Charters Towers area. Both sheet and gully erosion were identified.
>
> The effect of erosion in the upper Burdekin is reflected in the sediment loads of the river. Sediment yields ranging between 4.2 and 8.6 million tonnes annually occur in the upper Burdekin (B.P.C. 1976) representing a rate of

Episode 8

North-east Queensland 1970-1989



April 1969 – March 1970

April 1970 – March 1971

April 1971 – March 1972

April 1972 – March 1973

April 1973 – March 1974

April 1974 – March 1975

April 1975 – March 1976

April 1976 – March 1977

April 1977 – March 1978

April 1978– March 1979

April 1979 – March 1980

April 1980 – March 1981

April 1981 – March 1982

April 1982 – March 1983

April 1983 – March 1984

April 1984 – March 1985

April 1985 – March 1986

April 1986 – March 1987

April 1987 – March 1988

April 1988 – March 1989

Plate 2.10 Rainfall (1 April to 31 March) expressed as a percentile over the last hundred years for Episode 8. The El Niño years were 1969/70, 1972/73, 1977/78, 1982/83, 1987/88. The La Niña years were 1970/71, 1971/72, 1973/74, 1974/55, 1975/76, 1988/89.

Episode 8 – North-east Queensland 1980s

Time period: 1970 to 1996
Base period: 1975 – 1978

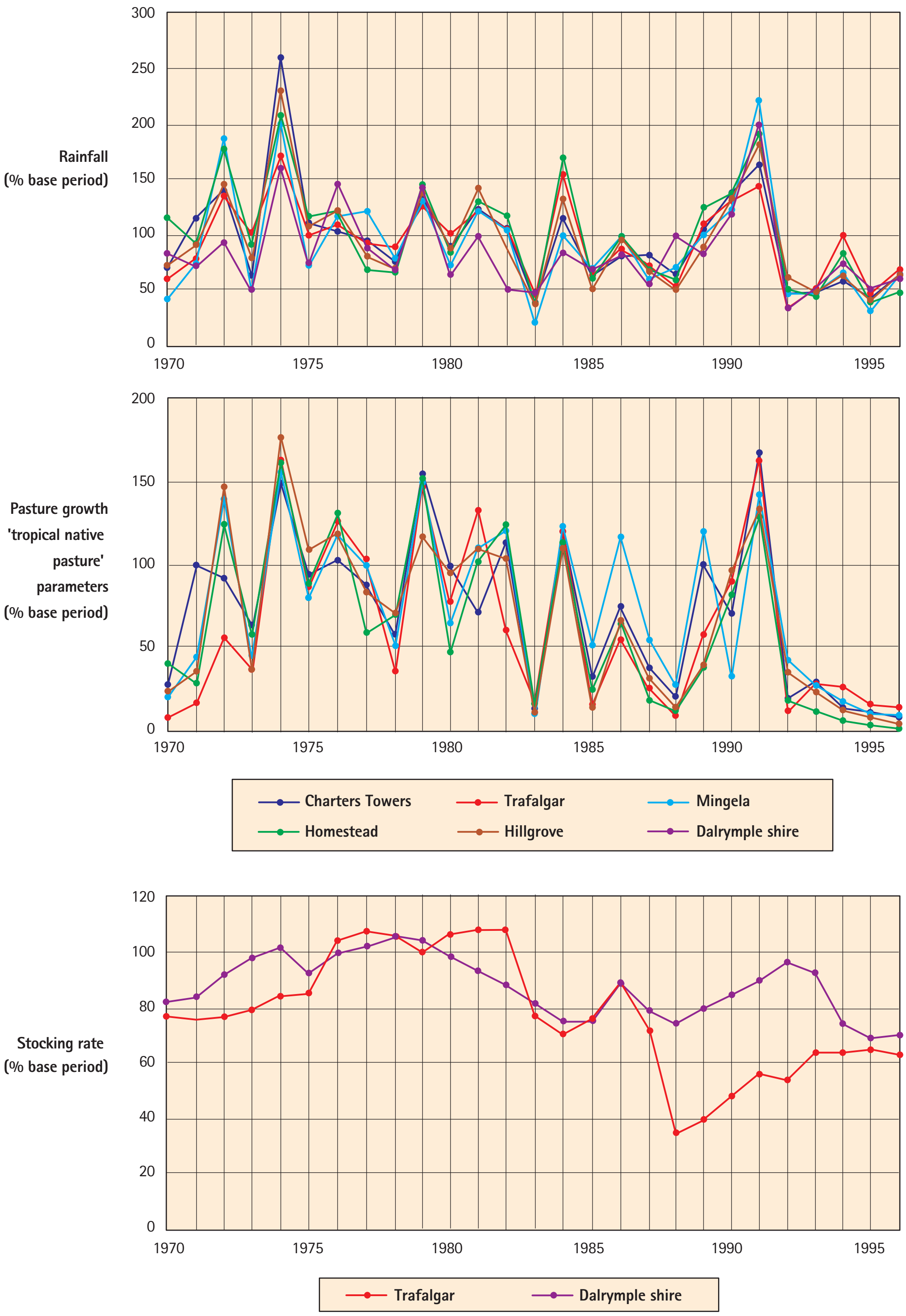


Figure 2.8 Episode 8 for north-east Queensland in the 1980s. Time series of: (a) rainfall; (b) simulated pasture growth using 'tropical native pasture' parameter set; and (c) reported stock numbers. The annual period is 1 April to 31 March. Data have been plotted with the X-axis being the 'year' at the end of the 12-month period. Data are expressed as a percentage of the mean of the base period 1974/75 to 1978/79. The year 1984/85 has been taken as the first year of the consecutive drought/degradation sequence.

> denudation of from 0.05 mm y^{-1} to 0.18 mm y^{-1}. These rates of denudation may generate total catchment loads up to 20 million tonnes per year (Cyril Crisolka *(sic.)*, [Ciesolka] personal communication, as reported in the Burdekin Project Ecological Study 1981 (B.P.E.S. 1981)). That report also provides data (Table 9.7, p. 163) on the components of the sediment - washload (that component of the sediment with a large settling time compared with large scale eddy motions of the flow, and consequently is reasonably uniform with respect to cross sectional depth and position), bedload and coarse sediments. About 16% of sediment occurs as bedload.
>
> The B.P.E.S. (1981) report (p. 170) indicates that the Burdekin Falls dam, presently under construction, will trap all the bedload and coarse sediment moving into its storage area, but the position with washload deposition is not so clear. The report states that 'if all the bedload and 30% of the washload estimated to pass Clare is trapped, the average annual volume (of deposition) is about 1.5 x 106 m^3 or 0.1% of the Stage 1 volume (1.75 million Ml). Whilst not having a great impact on the actual storage volume, the sediment comprises the most fertile portion of the Upper Burdekin landscape — its topsoil. Presently, much of this is deposited in the Burdekin Delta and much of the suspended sediment results in prograding of the coastline at the rate of about 1m per year or 1km per 1000 years (B.P.E.S. p. 169).
>
> On p. 653 of its report (BPC 1976), the Burdekin Project Committee recommends that 'more Australian research to quantify the erosion situation in particularly fragile environments, such as the Burdekin River catchment, should be encouraged'. A recent brief visit to the upper Burdekin by the authors of this present report, leads us to the conclusion that the natural erosion processes occurring in the area due to its geology and pedology have been accelerated by the activities of man. These activities include production of beef cattle, and provision of rural roads, the latter in particular being instrumental in concentrating runoff waters with gully erosion being the result. Some graziers are acutely aware of the erosion problem and are interested in ways of ameliorating the effects; most are not.
>
> LANDSAT imagery showed that at the end of the 1981 dry season, extensive degradation was present over a large portion of the upper Burdekin Catchment, particularly in the Charters Towers and Ravenswood districts. In May 1983 following late summer rains, whilst some of these areas did support ground cover, much of this cover was of an ephemeral rather than perennial nature — annual grasses and herbs. It is imperative that a detailed study be undertaken to collect base data which can be used in developing grazing management strategies designed to minimise degradation commensurate with a profitable beef industry.

Evidence of pasture composition change

High grazing pressure was maintained during the droughts 1977/78 and 1982/83. In the case of 1982/83, sales and deaths occurred when summer rains failed (e.g. P. Smith pers. comm.). The 1982/83 drought broke with good autumn rains resulting in good animal growth conditions (Landsberg *et al.* 1998). Pasture composition was in decline with large reductions in black speargrass (*Heteropogan contortus*) composition. The period 1984/85 to 1987/88 had generally low summer rainfall but intermittent winter rainfall sufficient to supply adequate animal nutrition (P. Smith pers. comm.). During this time the changes in pasture composition continued with the spread of Indian couch (*Bothriochloa pertusa;* Mortiss 1995, A.J. Pressland pers. comm.).

J. McIvor, now a senior pasture scientist in CSIRO, travelled widely through the shire in the 1980s:

> These changes from tall tussock grasses were also occurring elsewhere in the district and continued during the 1980s. We spent a lot of time in 1981-82 looking for sites for our ECOSSAT plots. Areas that were strongly dominated by tall tussock species at that time had become mixtures of Indian couch, short-lived perennial and annual grasses, and forbs by the late 1980s. Ground cover had also declined and runoff was rapid and brief: creeks 'ran dry or ten feet high' (and dry again) in one day.

S.M. Howden (1988, pers. comm.) has provided a likely sequence of ecophysiological events that would have resulted in the replacement of perennial tussock grasses of kangaroo grass and black speargrass with Indian couch:

> Heavy utilisation during summer drought (e.g. 1977/78, 1982/83, 1987/88) resulted in large reduction in a perennial grass basal cover. Autumn breaks (e.g. 1978, 1983, 1988) resulted in conditions for seed production of Indian couch. Seed dormancy was broken over the subsequent dry season, enabling germination and seedling establishment to occur at start of the next wet season (McIvor and Howden 2000) when competition from other perennial grasses was much reduced due to their low basal cover. Whilst not confined to the 1982-1984 period, nevertheless this climatic sequence provided such an opportunity for pasture composition change.

Indian couch replaced black speargrass particularly in the eastern area of the shire (Howden 1988, Mortiss 1995). Indian couch has a creeping growth habit that protects the soil from erosion once it has made early seasonal growth. It is resistant to grazing pressure and reasonably nutritious. For a given level of dry matter, Indian couch provides greater cover than native perennial grasses (Scanlan *et al.* 1996). Its disadvantage is that it does not provide a bulk of standing dry feed in winter or surface cover in extended droughts. J. McIvor (pers. comm.) observed that Indian couch increased rapidly after the 1987/88 drought had 'opened up' the pastures and was followed by a favourable year (1988/89) with low cattle numbers. He concluded that this combination of low grazing pressure and a good year following severe drought, provided the suitable sequence for the rapid increase to occur.

In ungrazed experimental plots, four times more soil movement was recorded on black speargrass plots than on Indian couch plots, and it was concluded that, under light stocking, a reduction in soil movement under Indian couch could be expected (Pressland 1990, Scanlan *et al.* 1996).

Remote sensing techniques are being developed to monitor the condition and trend of ground cover (as the converse of bare ground) to assess changes in surface condition in grazing lands (Plate 2.11). These satellite images show the impact of climate on surface condition, but the contrast across fence lines indicates the impact of different grazing pressures on recovery in favourable periods and loss of ground cover in drought or dry years.

Soil erosion and woody weeds

Previous reports had concluded that overgrazing was accelerating the natural erosion processes in the Burdekin Catchment. Mortiss (1995, p. 31) reviewed experimental trials:

> Overgrazing reduces plant cover on the soil and exposes it to the action of raindrops and water flow. To measure the effect of grazing pressure on ground cover and erosion, Scanlan *et al.* (1993), analysed data from grazed and ungrazed plots at several sites in Dalrymple Shire. The exclusion of domestic livestock resulted in more woody plant seedlings. Sheet erosion was greatly reduced by plant cover, whereas runoff was still relatively high at cover levels approaching 50% and the potential existed for gully erosion at intermediate levels of cover.
>
> On plots at 'Cardigan', established by CSIRO, results were similar. In small rainfall events, of low intensity, runoff and soil movement decreased as cover increased. Levels of 40% reduced soil movement and runoff to low levels. But, for long high intensity storms, cover had no effect on runoff, although it still reduced soil movement. Even at 40% ground cover, high intensity storms were capable of transporting large amounts of soil through suspended sediment [McIvor *et al.* 1995b].
>
> Retention of native timber is no guarantee of soil stability. Soil loss at the CSIRO site at Hillgrove has been measured as higher under trees and native vegetation than killed trees and improved pasture. The critical factors are stocking rate and resultant plant soil cover. Practical graziers have observed that at some sites there is more erosion under natural timber than on cleared areas. There is a possibility that on some properties natural timber has thickened up causing grass cover to decline and the soil to become unstable.

J.C. Scanlan (pers. comm.) noted that the problem was not due to the trees themselves, but caused by vegetation thickening. The problem is due more to the competitive effects of trees reducing pasture production and hence increasing grazing pressure if animal numbers are not reduced.

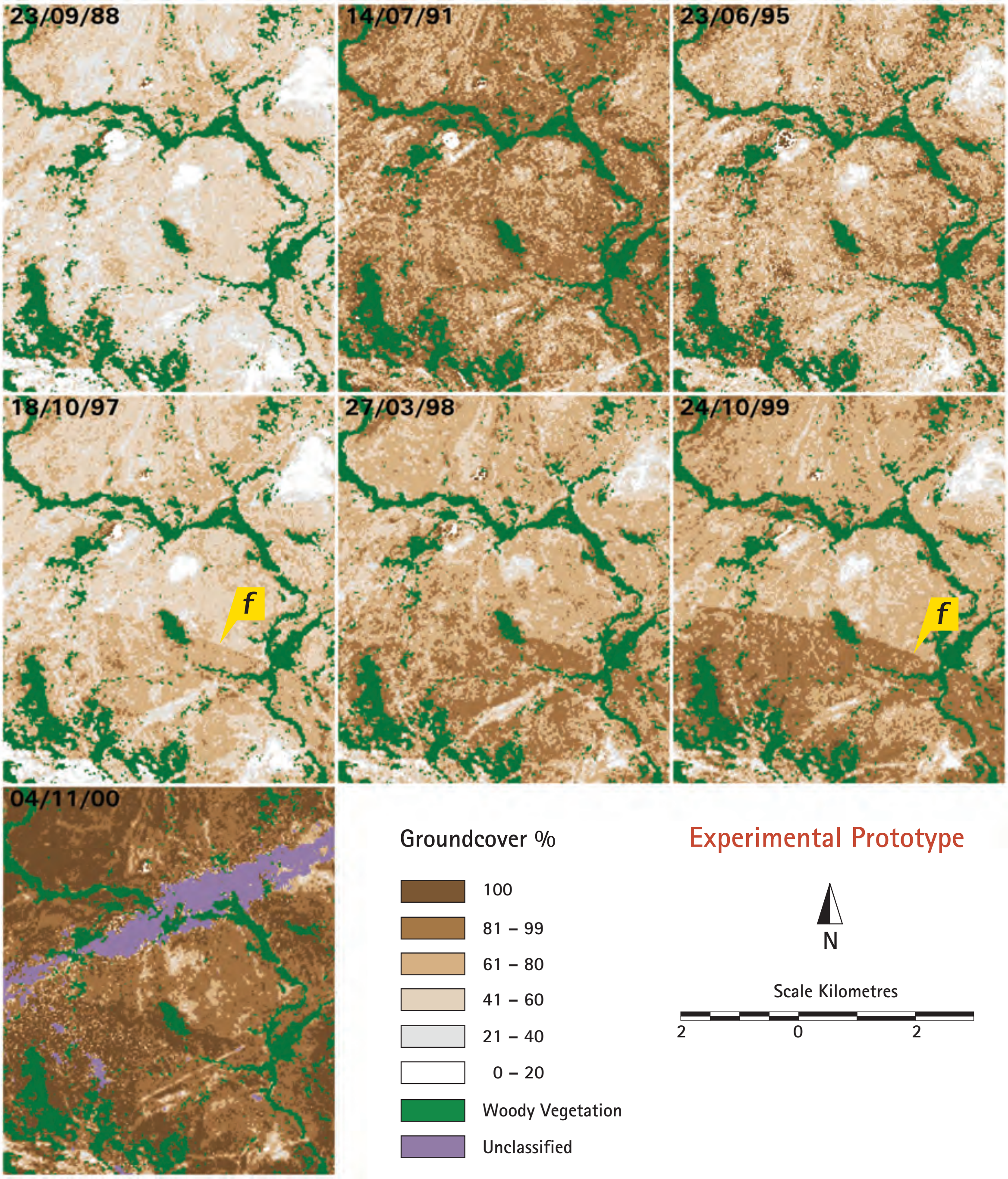


Plate 2.11 Ground cover estimated in the dry season from Landsat Thematic Mapper (TM) imagery for an area north of Charters Towers, Queensland (M. I. Byrne pers. comm. after Taube 1999, Taube *et al.* 2001).

The images show fluctuations in ground cover – at the end of the 1980s drought (low cover in1988), end of wet period 1989-91 (high cover in 1991), end of the early 1990s drought period (low to medium cover in 1995 and 1997), during and after the late 1990s sequence of wet years (medium to high cover in 1999 and 2000). Ground cover has been calculated from a multiple-regression using combinations of six spectral bands from different satellites. Images are subject to future revision and improvements to image processing and calibration. Nevertheless the approach demonstrates an emerging capability to monitor resource condition (e.g. bare ground) over time, and to identify the impact of different grazing management practices on resource condition through property/fenceline comparisons (e.g. ***f***, 1997 and 1999 images).

De Corte *et al.* (1991, 1994) surveyed eight different landscapes for soil erosion and woody weeds. There was some form of soil degradation on all landscape types (Mortiss 1995). For example, the 'percentage of sites' with scalds ranged from 14–63%. For sheet erosion, the percentage of sites ranged from 14–58%, with six landscape types having more than 30% of sites exhibiting sheet and scald erosion-types. Similarly six of the landscape types had more than 30% of sites with exotic and native weeds.

Recovery?

Good seasons occurred from 1988/89 to 1990/91, but an extremely severe drought period occurred from 1991 to 1995. Many of the degradation processes were already under way following the doubling of stocking rates in the mid 1970s. The droughts of the 1980s exposed and accelerated these degradation processes (Howden 1988, Gardener *et al.* 1990). However, lower stock numbers in the early 1990s may have slowed the processes. Mortiss (1995) suggests that shire stock numbers declined from 900,000 in 1986 to 300,000 in 1994 (part of the 1991 to 1995 drought), fewer than carried in the droughts of the late 1940s (1948) and 1951/52 (400,000).

J.G. McIvor recalls (pers. comm.):

> However the changes were not all one way or irreversible. After the 1988 drought, the good rains of 1989–1991 coupled with lower cattle numbers saw areas that had been bare for years revegetate and some of the tall tussock species became evident again. Fire had been widely used in the 1970s when smoke haze was widespread after the first rains of the wet season. There were very few fires through the 1980s but fire again began to be used in the 1990s although not on the scale of the 1970s.

The last word

In 1988 Trafalgar adopted the policy of reducing stock numbers to the same number as had been carried between 1920 and 1960 (Landsberg *et al.* 1998, p. 115). This courageous decision was not without financial pain:

> Gross margin patterns at Trafalgar over the past 15 years contrast with Australian Bureau of Agricultural and Research Economics farm income figures for the region. In the drought of 1982/83, Trafalgar sold many cattle while Shire cattle statistics indicate most properties retained stock, which would have required considerable supplementary feeding. This cost is reflected in the regional statistics as reduced farm income. Trafalgar sold much of their herd in 1987/88, which caused a temporary increase in gross margin. This was followed by a period (1989 to 1991) of poor financial performance as the station started to introduce its new management strategies and only slowly increased animal numbers to allow pastures to regenerate following the overuse they had received in the previous decade. In contrast, financial performances in the Shire were high during this same period as producers were able to capitalise on good seasons with high herd numbers that had been maintained with feeding during the 1987/88 drought. While financial performances were good during this 1989-91 period, pastures did not 'bounce back' completely and a large portion of the region entered the extended drought in 1991 in only fair or poor land condition (Tothill and Gillies 1992), with reduced potential pasture productivity. As a consequence of continual feed deficits over the last four years, financial performances of properties in the Shire have been declining rapidly. At the same time, gross margins at Trafalgar have been trending upwards as the financial benefits of improved management strategies are being realised. While some financial difficulties were experienced in the transition period of management … it is believed the long-term benefits will far outweigh the short-term stresses.

Earlier Landsberg *et al.* (1998, p. 111) compared pasture condition on Trafalgar with other areas of the shire:

> The wisdom of the decision not to rebuild herd numbers quickly following the 1987/88 drought is now evident when one looks around the Dalrymple Shire. While good seasons in 1989 and 1990 allowed pastures to recover well on Trafalgar given the low stock numbers, many properties in the district retained relatively high stock

numbers. Although pastures seemed to 'bounce back' on these properties, this was only in terms of short-term production, and not botanical composition. With the sequence of the driest years since European settlement experienced in the first half of the 1990s many properties have apparently lost a significant proportion of their perennial tussock grasses and with it potential pasture productivity, even if good seasons return. This extended drought from 1992 to 1996 also affected Trafalgar Station and while total standing dry matter and perennial grass percentage also declined, a good wet season in 1996/97 allowed pastures to significantly recover.

What do we learn for preventing land and pasture degradation?

1. Only half the droughts of this location have been associated with El Niño years. The 'other droughts', i.e. the summers of 1984/85 and 1985/86 in combination with favourable winters, were very important in amplifying degradation processes. The understanding of the climatic causes of rainfall distribution in these non-ENSO years would allow development of better forecasting systems for the region.

2. Degradation in response to heavy utilisation would appear to be unequivocal. Whilst the vegetation changes appear reversible, the loss of soil through water erosion is not. As Gardener *et al.* (1990) stated so insightfully, the solving of one problem (animal nutrition) caused another (loss of 'desirable' perennial grasses and soil erosion).

3. Episode 8 teaches us that degradation can occur even after a hundred years of apparently sustainable use of the natural grazing resource. Changes in grazing practices are continuing to occur and hence we should be alert to the possibility of future degradation episodes in environments so far considered relatively immune from the problems of climatic variability. The occurrence of Episode 8 after a hundred years of history and experience indicates that a fundamentally new approach will be required to prevent the 'ninth episode'.

2.10 Summary analysis of degradation episodes

The eight degradation episodes described in this chapter involved severe and extended drought periods (Table 2.10) that revealed and amplified the extent of resource damage. To produce a 'generalised degradation episode' we have determined subjectively an *initial drought year* for each episode using individual rainfall station data and pasture growth simulations (Figures 2.1 to 2.8). Episode 5 was not included in this analysis as it involved the infestation of woody weeds in response to a sequence of wet years in the 1950s with the main effect apparent in the mid 1960s drought.

Episode 1 (western New South Wales in 1890s) was divided into two sequences (Figure 2.1a, 2.1b). In the southern and central (Wentworth, Wilcannia) and western (Broken Hill/Menindee) regions the drought

Table 2.10. Period of severe drought in each of the seven degradation episodes involving drought.

Episode	Location	First Year	Last Year	Length
1A	Western NSW	1895	1902	8
1B	Western NSW	1897	1902	6
2	North-eastern SA	1927	1931	5
3	Gascoyne WA	1935/36	1940/41	6
4	South-western NSW	1943	1945	3
6	Central Australia	1960/61	1965/66	6
7	South-western Qld	1964/65	1965/66	2
8	North-eastern Qld	1984/85	1987/88	4

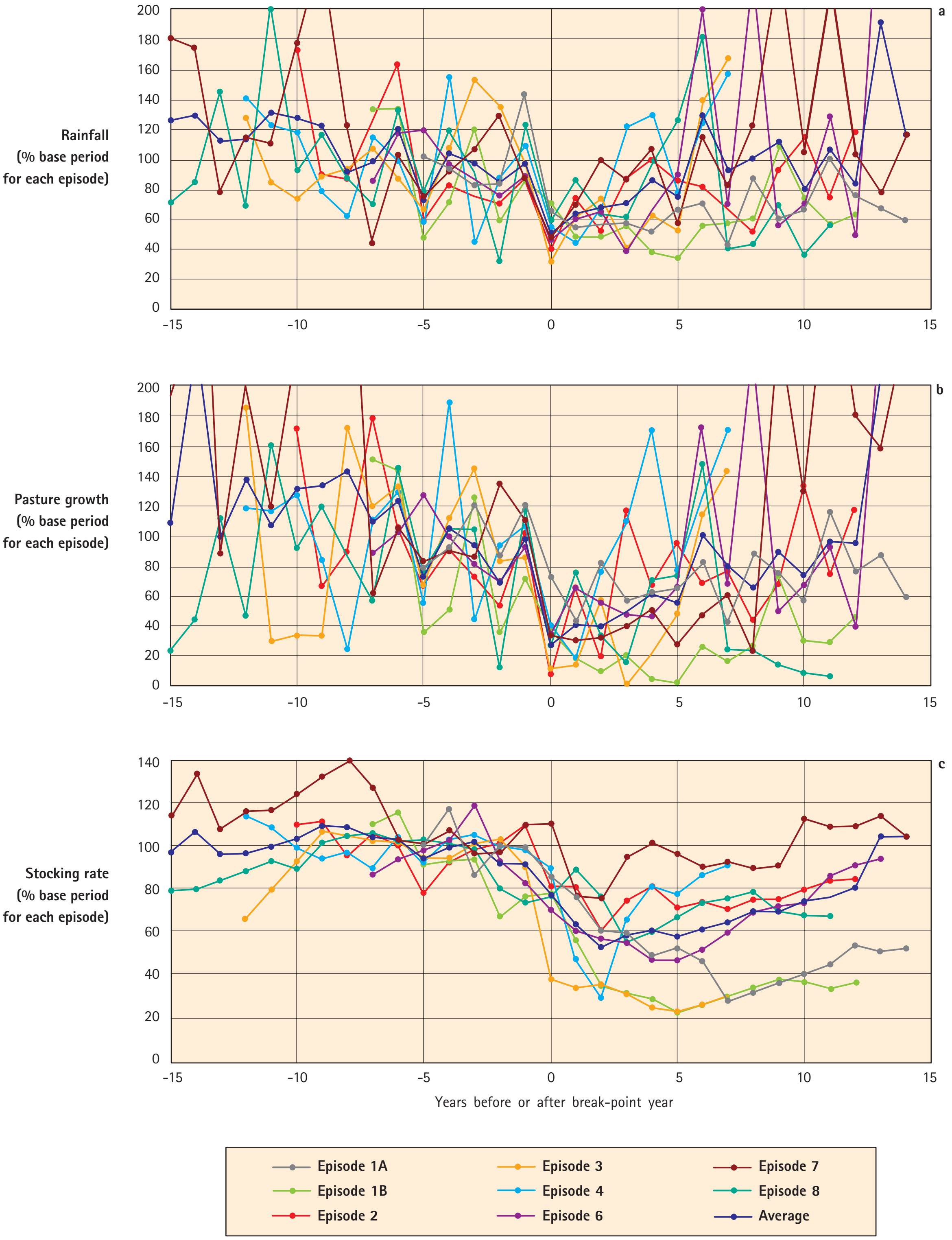


Figure 2.9 Comparison of time series of: (a) rainfall; (b) pasture growth: and (c) reported stock numbers across locations in each episode. Pasture parameter sets used for each episode were: 1A – Kinchega 'herbage'; 1B – 'perennial grass', 2 – Kinchega 'herbage'; 3 – Gascoyne 'herbage'; 4 – Kinchega 'herbage'; 6 – central Australian 'herbage'; 7 – 'perennial grass'; and 8 – 'tropical native pasture'. Episode 5 has not been included (see text). Average does not include Episode 1A.

sequence began in 1895 (January to December) and continued until 1902. In the north (Bourke) and east (Cobar) good rainfall occurred in 1896 and the year 1897 has been taken as the *initial drought year.*

In Episode 2 (north-eastern South Australia and western New South Wales in 1920s), 1927 (January to December) is clearly the *initial drought year.* Although Menindee had reasonable pasture growth in 1928, most of the locations in South Australia had low rainfall in 1928, 1929 and, in some cases, 1930.

In Episode 3 (Gascoyne, Western Australia in 1930s) the year 1935/36 (ending March 1936) was considered as the *initial drought year* and was generally severe without relief in 1936/37. The drought continued up to and including 1940.

Episode 4 (north-eastern South Australia and western New South Wales in 1940s) does not have a clear *initial drought year,* as severe droughts (e.g. 1940) are apparent in the lead-up period. Rainfall data and pasture growth simulations suggest that 1943 (January to December) was the initial drought year for the regions shown.

In Episode 6 (central Australia in 1960s) drought problems were emerging in the late 1950s. However average rainfall and simulated pasture growth occurred at some locations in 1959/60, and hence 1960/61 has been taken as the *initial drought year.* There was a brief recovery in early 1962 but then drought conditions continued until 1966.

In Episode 7 (south-western Queensland in 1960s) rainfall data suggest 1963/64 (ending March) as the *initial drought year* apart from Paroo shire. However pasture growth and observations (Miller *et al.* 1973) suggest that 1964/65 was the *initial drought year.*

In Episode 8 (north-eastern Queensland 1980s), the *initial drought year* is not clear. The summer of 1982/83 was particularly severe but was relieved by substantial autumn/winter rainfall. 1984/85 and 1985/86 had low summer rainfall but winter rainfall provided adequate animal nutrition. Based on consultation with Department of Primary Industries officers with first-hand experience (P. Smith, A.J. Pressland pers. comm.) and from pasture growth simulations we have adopted 1984/85 as the initial drought year.

Figure 2.9 represents a composite of the seven episodes scaled in time relative to the *initial drought year* (taken as year zero). Figure 2.10 averages the seven episodes and also presents a composite of episodes split on short-term droughts (Episodes 2, 4, 7, 8), and long-term droughts (Episodes 1A, 1B, 3, 6). For the purpose of averaging across the seven episodes we chose Episode 1B to represent Episode 1.

In the 10 years prior to the *initial drought year* most locations experienced single years with droughts or well above-average conditions. The *initial drought year* had rainfall 30–70% (mean of 60%) of the previous base period which, when expressed as simulated pasture growth, was 10–70% of the base period with a mean of 30% (not including Episode 1A). The drought phase lasted 2 to 6 years. Averaged across episodes, rainfall and pasture growth remained low for subsequent years (60–70% and 40–60% of base period, respectively). On average, rainfall and pasture growth did not return to more than 90% of the base period rainfall until years 6 and 7.

The differing time series of relative stock numbers indicate that patterns of stock numbers alone cannot be used to identify the causes of degradation. Properties using conservative stocking and those degrading the resource by retaining high stock numbers could have the same relative pattern in terms of stocking rate management in response to drought. In both cases, stocking rates were maintained but in the latter case, there were longer-term consequences involving resource degradation. Similarly, highly 'responsive' graziers who dramatically reduce stock numbers at the onset of drought will have similar patterns of stock numbers

Figure 2.10 Average time series of: (a) rainfall; (b) simulated pasture growth; and (c) stock numbers for degradation episodes from Fig. 2.9 involving drought. Episode 5 has not been included (see text). The time axis is given relative to the *initial drought year.* Three time-series are shown: Average of the seven degradation episodes involving drought (from Figure 2.9, with Episode 1 represented only by 1B); Average of four episodes (2,4,7,8) with short drought periods; and Average of four episodes (1A,1B,3,6) with long drought periods.

to those properties where previous degradation has caused the loss of perennial vegetation and stock losses and/or destocking occur very quickly with the onset of drought (Jennings *et al.* 1979).

Figure 2.10 compares the average of time series for episodes with short-term (2 to 4 years; Episodes 2, 4, 7, 8) and long-term (>4 years; Episodes 1A, 1B, 3, 6) droughts. For 'short drought' episodes, rainfall and simulated 'potential' pasture growth (i.e. without degradation effects) returned to near base period values by year 4 after the *initial drought year*. Animal numbers returned to 80% of the base period. For the 'long drought' episodes, rainfall and 'potential' pasture growth returned to base period values by year 6 after the *initial drought year*. However, stock numbers remained low at 40% of the previous base period. A variety of reasons are possible including a loss of plant productivity, more cautious management in restocking and low financial capability for buying stock. The property and district livestock data used in constructing the composites included a wide range of stocking strategies from sustainable to over-grazing. Thus, at this stage of our research the composites (Figure 2.10) demonstrate the overwhelming impact of drought on subsequent livestock numbers rather than just the impact of degradation of the resource. Current research is addressing the issue of separating climate and grazing management effects.

The relationship between rainfall, pasture growth and safe carrying capacity can be quantified by combining graziers' estimates of 'safe' carrying capacity with simulated pasture growth. For semi-arid rangelands in south-west Queensland the 'safe' estimates represent an average of about 15% utilisation without considering other herbivores. However, actual stocking rates reported in individual years are closer to 20–40% utilisation of pasture growth (Scanlan *et al.* 1994, Johnston 1996, Hall *et al.* 1998). These levels are in agreement with economic optimal stocking rates found using combined herd/pasture growth simulation models (Stafford Smith *et al.* 2000). Short-term (<10 years) grazing trials show animal production per ha is maximised at even greater levels of utilisation (40–60%, Day *et al.* 1997). Thus there is little obvious short-term penalty for high utilisation rates especially in the sequences of good years that preceded the degradation episodes. However, such stocking rates can prime the system for degradation to occur during drought.

If some graziers had stocked up in the sequence of good years in an attempt to maximise income, it is plausible that the historical stock numbers during the base period represent utilisation rates of 30–40% of pasture growth (without including other herbivores). The single-year droughts during the pre-degradation episode would have had high grazing pressure but any damage would have been masked by a return of favourable rainfall conditions. However, the retention of stock during the drought phase indicates that pasture growth on average was reduced to 40% of the base period whilst, on average, stock numbers were 60% of the base period (higher if Episode 3 is not included). Thus utilisation rates of pasture growth during the drought phase were likely to be 45–60%, sufficient to damage perennial species and remove the protective surface cover of the soil. The retention of stock during the recovery phase would further exacerbate the grazing pressure on remaining perennial plants and regenerating seedlings (e.g. Mott *et al.* 1992).

Thus we might conclude from this consideration of 'composite' degradation episodes that there are three major causes of degradation:

1. over-utilisation by domestic and other herbivores in pre-drought period resulting in damage to 'desirable' perennial species as evidenced by the rapid collapse in stock numbers with the onset of severe drought (e.g. Episodes 3, 4);
2. extreme utilisation in first years of drought by retaining stock (and presence of other herbivores) that caused the loss of perennial species and soil cover, exacerbating the effects of drought in subsequent years (Episodes 2, 6, 7, 8); and

3. continued retention of stock through a long drought period compounding damage to the resource and delaying recovery (Episode 1 and to a lesser extent Episode 3).

Such an analysis also provokes the question as to what could have been done differently to prevent or reduce the observed damage. As some authors (Chippendale 1963, J.G. McIvor pers. comm.) have strongly asserted the first step is that graziers will have to accept that the belief 'the country always comes back' is not true. Production in years after a drought may be higher than during drought years, suggesting that the belief is true, but production will be below potential in subsequent years (e.g. Ash *et al.* 2002, p. 24).

Those graziers whose experiences have been recorded (Anon. 1951, Lilley 1973, Purvis 1986, Lange *et al.* 1984, Landsberg *et al.* 1998, Lauder 2000a, 2000b, Stehlik 2003, Wahlquist 2003) emphasise the adoption of conservative stocking rates, and/or highly responsive stock management as strategies to prevent degradation. However, some graziers may feel compelled, presumably by property size and economics, to push the grazing and animal resources to their limits. The above three causes of resource damage suggest that such graziers could benefit by some warning of the risks of degradation.

W.H. Burrows (pers. comm.) recalled the following 'best advice I've heard for grazing land management over the last 40 years'.

> I went to a stock supplement 'Field Day' at *Hythe*, Charleville in the middle of the '65 drought. After the day's proceedings someone asked the owner, Minter Lethbridge, how was it that his country was in such good nick? Minter said that when his old man handed over management of *Hythe* he told his son the only thing he needed to do 'was to come out of each drought, no matter what its duration, with a good cover of [pasture] stubble on the ground' – and so he destocked whenever that looked like occurring and waited the drought out.

2.11 Conclusion

The extended drought periods in each degradation episode have provided a test of the capacity of grazing systems (i.e. land, plants, animals, humans and social structure) to handle stress. Evidence that degradation was already occurring was identified prior to the extended drought sequences. The sequence of dry years, ranging from two to eight years, exposed and/or amplified the degradation processes. The unequivocal evidence was provided by: (a) the physical 'horror' of bare landscapes, erosion scalds and gullies and dust storms; (b) the biological devastation of woody weeds and animal suffering/deaths or forced sales; and (c) the financial and emotional plight of graziers and their families due to reduced production in some cases leading to abandonment of properties or, sadly, deaths (e.g. McDonald 1991, Ker Conway 1989).

We conclude from this study that there are four components necessary to prevent degradation of the grazing resource:

1. a commitment of graziers to manage stock (and fire), against a background of high climate variability, to prevent degradation of the perennial pasture resource;
2. government policies which facilitate and value graziers' actions in moving to more sustainable grazing systems;
3. an alert system based on climatic understanding, ecosystem response and resource monitoring which provides warning before damage occurs rather than a retrospective analysis after the event; and
4. financial systems that allow graziers to maintain cash flow during drought and support management actions aiding pasture resource recovery after drought.

Chapter 3

Modelling climate and management effects on shrub populations in the Gascoyne region of Western Australia and the North East District of South Australia

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3.1 Introduction

A major question raised by the historical degradation episodes is to what extent they could have been avoided or mitigated by better grazing management. During and following the severe drought periods of the degradation episodes it was debated whether the soil erosion and loss of 'desirable' perennial shrubs and grasses were the result of the extremes of climatic variability or caused by too many animals. For example, during the 1920s/30s episode in South Australia and western New South Wales the loss of shrubs and grasses was attributed by some observers at the time to the severity of drought rather than overstocking (Condon 2002, p. 212). Alternatively, Ratcliffe (1970, p. 196) summarising his findings during the 1930s in South Australia, wrote:

> The fact that the 'bush' had been eaten too much during the lean years when other feed had failed turned out to be the key to the problem of drift and erosion. Over-grazing had killed and destroyed the bush over thousands of square miles of country; and when the plant cover had disappeared, the soil lay unprotected at the mercy of the wind.

In reality, it is not one or the other. Climatic variability and grazing pressure interact. One approach to the debate is to use computer models that represent the impact of both climate variability and stocking rate decisions on attributes of the pasture resource such as perennial grass basal cover, shrub density, pasture composition, soil loss, soil nutrients and infiltration properties. These models integrate much of the scientific understanding of the processes of degradation and recovery, and then, through simulation experiments, allow climate and management effects to be quantified.

Simulation experiments have already been used to model aspects of the degradation episodes. For example, in describing the impact of Episode 8 (north-east Queensland 1980s) on the grazing property Trafalgar, Landsberg *et al.* (1998) reported results from a model in which pasture composition (% 'desirable' perennial grasses) was calculated from the history of pasture utilisation (defined as the annual animal intake relative to pasture growth). The model was derived from grazing management field trials in the region (Ash *et al.* 1996). For the period 1920 to 1997, the impact of annual stocking rates used on Trafalgar was compared to relative stocking rates reported for the Dalrymple shire (Landsberg *et al.* 1998). The simulation results confirmed: (1) the deleterious impact that the combination of high stock numbers and low rainfall in the 1980s had on pasture composition; and (2) the pasture recovery achieved by reducing stock numbers dramatically in 1988 on Trafalgar, in contrast to the further deleterious impact resulting from continued stocking at the higher levels reported in shire statistics. Other simulation studies have evaluated the economic and environmental consequences of different grazing management strategies, including the use of seasonal forecasting (McKeon *et al.* 2000, Ash *et al.* 2003).

Models of this type are currently being developed for many of the degradation and recovery processes including processes specific to the vegetation and soils of each rangeland region. These models combine knowledge from formal scientific field trials, monitoring of long-term sites and observations of graziers and scientists. They provide a basis for analysing the causes of degradation and the strategies for reducing it in the future.

In the following sections, we present modelling studies for shrub communities in the Gascoyne region of Western Australia and the North East District of South Australia (i.e. the North East Soil Conservation District). In these regions, many shrubs are palatable and an increase in density is regarded as a desirable outcome, while a decrease in shrub density is viewed as a decline in resource condition from a pastoral perspective. Range condition is synonymous with the density of 'desirable' shrubs expressed relative to the potential of the particular vegetation type (Hacker *et al.* 1991). However, we note that in much of Australia, shrub increases are regarded as a form of degradation. This is because the shrub species that increase are 'undesirable' from a pastoral perspective. For example, in the Western Division of New South Wales and south-western Queensland, an increase in (non-chenopod) shrub density is viewed as resource degradation since the increase is generally due to an increase in 'woody weeds' rather than 'desirables' (e.g. Episodes 5 and 7 in Chapter 2).

The decline in 'desirable' shrub density contributed to the degradation episodes (north-eastern South Australia and Gascoyne, Western Australia) described in Chapter 2. In these regions, shrubs provide a key role (Chapter 1.6.2) in protecting the soil surface from erosion and providing feed for livestock. During extreme droughts such as between 1935 and 1937 in the Gascoyne, or the late 1920s and again in the 1940s in North East South Australia, the shrub component provided the only feed available. This chapter concludes with results from monitoring sites in the southern rangelands (especially the Gascoyne–Murchison area) of Western Australia where large increases in shrub density and changes to other shrub attributes have occurred during the 1990s and early 2000s. Together the modelling and monitoring studies provide a case study for historical assessment of successes and mistakes as well as opportunities for improved management in the future.

3.2 Modelling methods and limitations

Two shrub dynamic models have been developed either from short-term (10-year) grazing trials (WALTER, Watson 1999a) or from a range of shorter- and longer-term (20-year) data from grazing trials, monitoring programs and exclosures (IMAGES, Hacker *et al.* 1991). These were used independently to simulate long-term (century scale) dynamics in shrub density. The accuracy of these models in application over a hundred years is unknown. An important limitation to their use over long periods is that, unlike models that simulate herbage or grass biomass, shrub dynamics models do not allow the frequent resetting of populations to zero or very low values. Therefore, modelling or parameter errors are more likely to accumulate over time. Furthermore, demographic stochasticity – particularly of recruitment (i.e. recruitment can be patchy and random at small plot scale) makes comparisons difficult between model output and actual populations from small plots from which model parameters were derived (Watson 1998). Nevertheless, the models and parameters represent currently available scientific information and provide a transparent and reproducible approach to separating climate and management effects.

Areas modelled

The site modelled for Western Australia can be considered a typical property in the north-western part of the Gascoyne district, inland from the coast. In South Australia, simulations were undertaken for the north-western part of the region covered by the North East Soil Conservation District Board. The areas chosen for the simulations should be regarded as representative of the regions rather than as specific locations.

Species modelled

Both models for both locations used parameter sets based on the shrub *Eremophila maitlandii* F Muell. ex Benth. (tall poverty bush), which was used to represent a generic 'desirable' shrub. *E. maitlandii* is palatable to livestock and relatively long-lived. Ehrlén and Lehtilä (2002) calculated a conditional lifespan for this species of 84.5 years using data from Watson *et al.* (1997b). Populations decline in density during drought and under heavy grazing, while recruitment can be continuous and relatively rapid.

Period modelled

The initial WALTER model runs were from 1889 to 1997, using rainfall data from single Western Australian and South Australian locations (Chapter 5 in McKeon and Hall 2002). Subsequently, the model runs were extended to 2002 using rainfall from the same locations. This latter period coincided with the highest 10–year moving average of annual rainfall (April to March) for the Gascoyne, and the Gascoyne location used in the WALTER and IMAGES simulations, since pastoralism began (Fig 3.1).

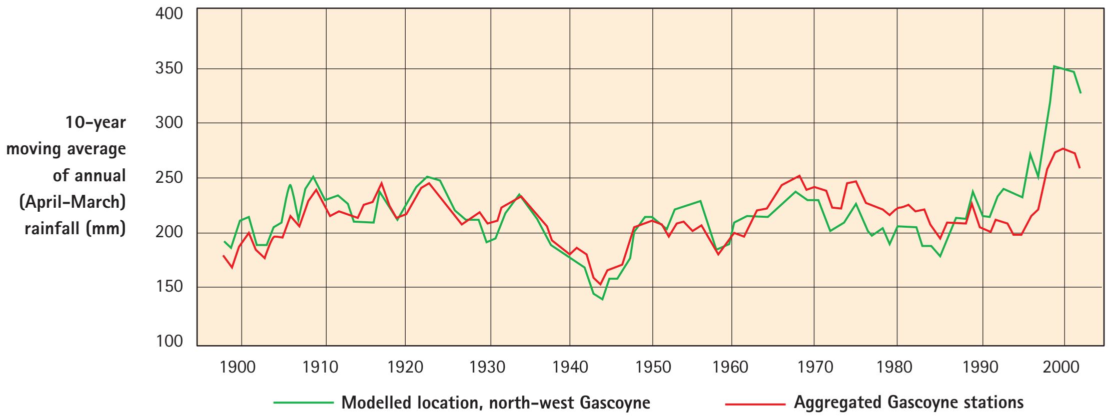

Figure 3.1. 10-year moving average of annual (April–March) rainfall in the Gascoyne, Western Australia. The plot shows the moving average for an aggregation of rainfall stations in the Gascoyne (as shown in Chapter 1, Plate 1.2) and for the single north-west Gascoyne location used in the model simulations.

Qualitative validation

Given the long periods involved, independent data with which to validate the models are scarce. Monitoring systems, such as the Western Australian Rangeland Monitoring System (WARMS) can provide some qualitative validation of particular periods. For example, recent analyses (Watson and Thomas 2003) indicate substantial increases in shrub density at many locations, providing qualitative validation of the WALTER model over the period 1993 to 2001. Less intensive data, but over a longer period, are available through the analysis of long-term historic photos in North East South Australia (McDonald and Lay 2002). A set of photos, first taken during the period 1943 to 1967, provide an indication of change between then and the period 1995 to 1998.

3.2.1 The WALTER model – technical description

WALTER is a time-varying transition matrix model that simulates the dynamics of a single species on an annual time-step. It is based on matrices containing one age-class representing recruits (YOUNG) and three mature stage-classes based on canopy height (SHORT, MEDIUM, TALL). Stage- rather than age-classes are used because the long-lived characteristics of these shrubs make it impossible to determine their age and because the use of stages allows individual shrubs to move between any of the mature stages. For example, shrubs can grow from SHORT to MEDIUM but can also decrease from MEDIUM to SHORT. Shrubs generally decrease in size due to grazing or drought. Recruitment rates are expressed as functions of MEDIUM and TALL densities, with no density dependence. No recruits are possible from SHORT or YOUNG stages.

Transition matrices were used for two stocking rates (HIGH and LOW) and three year-types (Ordinary, Dry-Effect and Wet-Effect) using values for *E. maitlandii* from Watson *et al.* (1997b). LOW stocking was used to represent rates less than those recommended by natural resource management agencies, i.e. the assumption can be made that LOW stocking permits a sustainable grazing system. HIGH stocking can be regarded as occurring at rates higher than those recommended and can be expected to cause resource degradation if maintained for too long or during drought.

The allocation of each actual year to a model year-type was simple and was subjectively based on the total amount of rainfall for each year in comparison to the long-term record and also on the total amount of rainfall in the preceding and succeeding years. Year-types were allocated in approximately the following proportions for each location: Ordinary 0.59; Dry-Effect 0.16; and Wet-Effect 0.25, based on the original modelled period of 1889 to 1997. The period (1984 to 1993) over which parameters for the model were determined contained a drought (1987/88) whose return time was inferred to be longer than that of the Wet-Effect year (1984) encountered during the same period (Watson *et al.* 1997a, 1997b). Thus the proportion of Wet-Effect years was higher than for Dry-Effect.

The subsequent simulations, when the years 1998 to 2002 (inclusive) were added, assumed that these five years were independent of the previous 109. This marginally altered the proportion of year types, for the Gascoyne only to: Ordinary 0.57; Dry-Effect 0.16; and Wet-Effect 0.27. No alteration was required for the South Australian location.

Detailed demographic information for *E. maitlandii* was presented in Watson *et al.* (1997a, 1997b). It can be briefly summarised as follows. Recruitment was possible during all three year-types, but was about eight times higher in Wet-Effect years than in Ordinary or Dry-Effect years. Recruitment rates were independent of stocking rate. YOUNG, SHORT and MEDIUM stages had similar mortality rates for each stocking rate by year-type combination. The TALL stage had much lower mortality rates than the other stages. Mortality during Dry-Effect years was about three times that during Ordinary years. Mortality during Wet-Effect years was lower than in either of the other two year-types. HIGH stocking approximately doubled mortality rate in comparison to LOW stocking. The rate of transition from the YOUNG stage to any of the mature stages was higher in Wet-Effect years than in Dry-Effect years for HIGH stocking. Under LOW stocking the total transition rate was the same in Wet-Effect and Dry-Effect years but a greater proportion entered the MEDIUM stage (having bypassed the SHORT stage) during Wet-Effect years. During Dry-Effect years and under HIGH stocking a greater percentage of mature individuals made transitions from taller to shorter stages (e.g. TALL to MEDIUM) than in Wet-Effect years or LOW stocking. The complete transition matrices can be found in Table 1 of Watson *et al.* (1997b).

For single year transition matrices, the annual population growth rate (APGR) can be derived analytically, before running the model. In matrix algebra terms, it is the dominant eigenvalue of the matrix (Caswell 1989). APGRs for each of the six transition matrices (i.e. HIGH and LOW stocking by three year-types) ranged from 0.838 for HIGH stocking in Dry-Effect years to 1.056 for LOW stocking in Wet-Effect years (Table 3.1). These rates are approximations only, since they assume that a stable stage distribution has been reached, as occurs when a single transition matrix is projected through time. However, in time-varying models, the stage structure never reaches equilibrium. Note that under both HIGH and LOW stocking, populations could only increase (i.e. APGR greater than 1.0) during Wet-Effect years.

Grazing strategies

Stocking rate was determined for each year based on the six grazing strategies outlined below:

1. **Constant LOW stocking.** In this scenario the stocking rate was kept constant, but conservative.
2. **Constant HIGH stocking.** In this scenario the stocking rate was kept constant, but high.

Table 3.1. Annual population growth rate (APGR) for each year-type by stocking rate.

	Annual population growth rates		
Stocking rate	Ordinary year-type	Dry-Effect year-type	Wet-effect year-type
LOW	0.989	0.925	1.056
HIGH	0.948	0.838	1.021

3. **Responsive – sensitive.** The aim of this management strategy was to protect newer plants from excessive grazing and to reduce the effects of grazing on older shrubs, since these provide seeds for further recruitment and the maintenance of large shrub size provides a drought resource.

   The size structure of the population of 'desirable' shrubs was used as an indicator of the need to lighten stocking rate. The stocking rate was set to HIGH while the proportion of SHORT plants was less than 20% of the total mature population. When the proportion of small plants became greater than or equal to 20%, the stocking rate was reduced to LOW.

   The proportion of SHORT individuals in the population will increase for two reasons. Firstly, there is an increase in the number of YOUNG plants making the transition into the mature population. Management is directed towards the protection of these plants from over-grazing. Secondly, a decrease in size of individuals caused by grazing or drought will lead to an increase in the average mortality rate of the entire population and a decrease in the reproduction rate, since SHORT plants do not provide recruits in the model. This stocking rate 'trigger' was reasonably sensitive. Under the baseline year-type frequencies reported for LOW stocking by Watson *et al.* (1997b), the average proportion of SHORT individuals in the population was 12%.

4. **Responsive – insensitive.** In this strategy, the stocking rate was set to HIGH while the proportion of SHORT plants was less than 50% of the total population. When the proportion of SHORT plants became greater than or equal to 50% the stocking rate was reduced to LOW. This strategy would represent a management regime that lightens stocking pressure only when the signs to do so are very obvious.

5. **Perfect knowledge – conservative.** In this scenario and the next, stocking rates were set using knowledge of the coming season, that is, it is assumed that perfectly correct climate forecasts of the next season are available and that management responded to these forecasts. The stocking rate was set to LOW in Ordinary and Dry-Effect years, but was set to HIGH in Wet-Effect years.

6. **Perfect knowledge – heavy stocker.** As for Strategy 5 above, but stocking rate was set to HIGH in Ordinary and Wet-Effect years and was reduced to LOW only in Dry-Effect years.

Effect of seasonal sequence

In order to examine the effect of the particular sequence of seasons experienced during the last 114 years, the model was run 5,000 times using a random selection of year-types. Although the selection of each year-type for each year was random, the total proportion of years for each year-type was maintained as for the actual year runs (for the extended run to 2002) i.e. Ordinary = 0.57, Dry-Effect = 0.16, and Wet-Effect = 0.27.

Comparison between locations

Identical parameterisations were used for each location to represent a generic 'desirable' shrub. The proportion of year-types over the period of model run was also identical, although the sequence of year-types was location dependent. This meant that the pattern and timing of change was different at each location, but the outcome in terms of final shrub densities was almost identical. Running the model with a random sequence of year-types provided identical results for each location. Therefore results for all six grazing strategies and random runs are presented for the Gascoyne site only.

3.2.2 The IMAGES model – technical description

The IMAGES model (version 2.1, Yan and Wang 1996) allows the modelling of five functional groups of shrubs as well as green and dry herbage. For this analysis, IMAGES included four perennial functional groups using a parameter set derived for the AussieGRASS project (Watson 1999b, Richards *et al.* 2001), based on data from the Boolathana grazing trial (Watson *et al.* 1997a, Holm *et al.* 2003). A subset of these data was used for the WALTER model. The output for only one of the functional groups, representing *E. maitlandii*, the generic 'desirable' species, is presented here.

IMAGES runs on a four-monthly time step: January–April, May–August and September–December (Hacker *et al.* 1991). The WATBAL model (Fitzpatrick *et al.* 1967) is used to generate the number of wet pentads (five-day periods) for each of these four-monthly time steps using daily rainfall data and average monthly evaporation data. IMAGES does not allow the modelling of various grazing strategies since stocking rate is provided at the outset and cannot be altered during the model run. For the purposes of this analysis the model was run at two stocking rates: 1) a light stocking rate representing a sustainable system; and 2) a heavy stocking rate, representing a grazing system that would degrade over time.

Preliminary modelling with IMAGES over the period of pastoral history showed that the model allowed populations of desirable species to regenerate to maximum densities following drought even when stocking rates remained high. Observations and field trials indicate that the ability of shrub populations to recover to previous maximum density is impaired by low seed populations, lower recruitment rates and loss of potential plant productivity (and density) through loss of soil nutrients, depth and infiltration attributes (e.g. Chapter 1). To represent explicitly this likely decline in potential shrub density, IMAGES was run in three stages for heavy stocking. Following each of the first two major droughts, the maximum density of shrubs for all four functional groups was reduced by one-third. For the Gascoyne, this reduction was made in 1906 and was further reduced in 1947. From 1906 the maximum density allowed was two-thirds of that in 1900. By reducing this density by another one-third the maximum density from 1947 was 45% of that in 1900 (i.e. 0.67 x 0.67 = 0.45). For the South Australian simulation, the maximum density was reduced in 1906 and again in 1938.

The reduction in maximum potential plant density after each major drought episode was explicitly included to represent observations of soil loss at the time (e.g. Ratcliffe 1936) or inferred from surveys (Wilcox and McKinnon 1972). It also reflects the comments by Beadle (1948) and Jennings *et al.* (1979) that this type of country had a reduced carrying capacity following severe degradation episodes. Thus the simulations of shrub density after these episodes at HIGH stocking rate reflect this parameterisation and are not the result of the processes of shrub dynamics included in the model.

3.3 The WALTER model – outputs and discussion

Under LOW stocking, the density of the modelled shrub population declined by about 16% during the period of pastoralism (Table 3.2 and Figures 3.2 and 3.3). However, it needs to be emphasised that this should not be used to provide an assessment of whether or not pastoralism is sustainable. Firstly, the parameter set was derived from a 10-year period during the Boolathana grazing trial in which average annual rainfall was exceeded in only one year and the general sequence of years could best be described as fair (Watson *et al.* 1997a). During the simulation, APGRs exceeded 1.0 only in Wet-Effect years. In the other 73% of years modelled, the APGR was less than 1.0. Secondly, the proportion of year-types affects the average APGR. Increasing the proportion of Wet-Effect year-types (or decreasing the proportion of Dry-Effect year-types) would increase the average APGR. However, it is not possible to precisely determine the correct proportion of year-types. Small changes in the 'rules' used would alter year-type proportions sufficiently to produce an average APGR greater than 1.0 over the period modelled. Thirdly, the average APGR was 0.998 under LOW stocking. This small deviation from 1.000 has a large cumulative effect when run at century time-scales. The model does not have the precision to differentiate between such a small annual (but large cumulative) difference.

Table 3.2. WALTER model outputs for north-west Gascoyne.

Simulation details	Initial (1988) density (plants/ha)	Final density (plants/ha)	Average[1] APGR	Years @LOW stocking rate	Years @HIGH stocking rate
Grazing strategy					
1. Constant LOW stocking rate	1,000	837	0.998	114	0
2. Constant HIGH stocking rate	1,000	3	0.950	0	114
3. Responsive – sensitive HIGH stocking until SHORT stage ≥20% of adult population.	1,000	282	0.989	95	19
4. Responsive – insensitive HIGH stocking until SHORT stage ≥50% of adult population.	1,000	16	0.964	36	78
5. Perfect knowledge – conservative LOW stocking Ordinary; Dry HIGH stocking; Wet.	1,000	389	0.992	83	31
6. Perfect knowledge – heavy stocker HIGH stocking Ordinary; Wet LOW stocking; Dry.	1,000	15	0.964	18	96
Random year sequences					
Random year sequence at constant LOW stocking rate. Average of 1,000 runs.	1,000	893	0.999	114	0
Random year sequence at constant HIGH stocking rate. Average of 1,000 runs.	1,000	3	0.951	0	114

[1] Average APGR is the Annual Population Growth Rate averaged over the 114 year period.

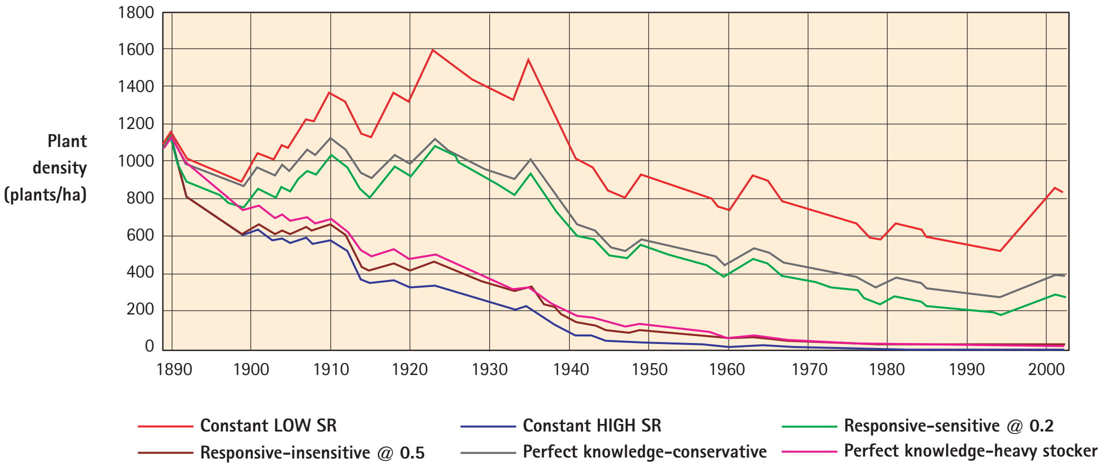

Figure 3.2. WALTER model runs for north-west Gascoyne site, Western Australia.

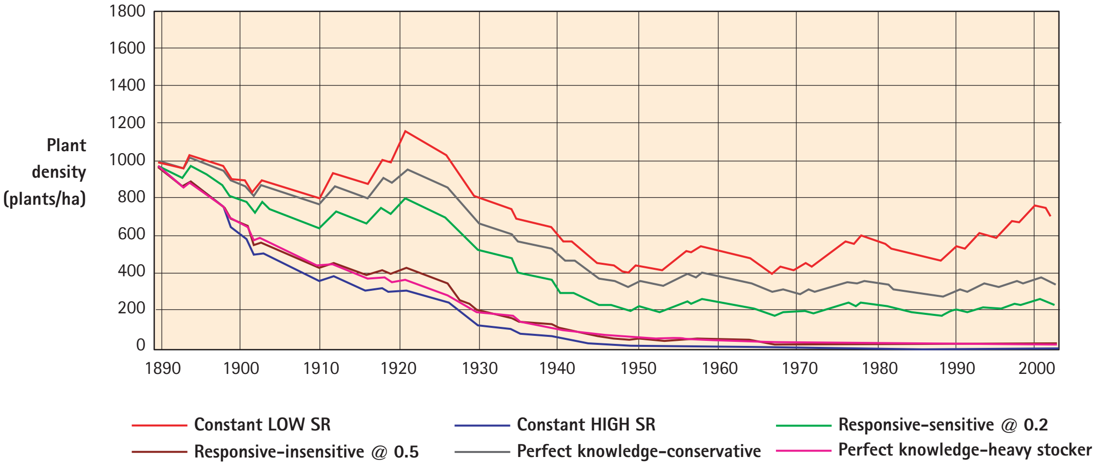

Figure 3.3. WALTER model runs for the North East District, South Australia.

3.3.1 Gascoyne, Western Australia

Patterns of change

The model output suggests that under LOW stocking, the drought of 1935 to 1940 caused the greatest decline in shrub population (i.e. reduction in density of 48% between 1935 and 1947) during the history of pastoralism, in this case 114 years. Degradation under HIGH stocking began in the early years of pastoralism and substantial reductions in population had already occurred before the 1935–1940 drought (Figure 3.2).

Three earlier periods were shown to have contributed to the decline in populations under HIGH stocking. These were 1891–1899, 1912–1914 and 1923–1933. All three periods were recognised as containing droughts (Fyfe 1940). However the surprising aspect is that under HIGH stocking these earlier droughts caused declines of similar magnitude to the late 1930s drought. This is not to suggest that the earlier droughts were of similar severity to that of the late 1930s, rather that by the late 1930s, substantial degradation had already occurred in those areas where high stocking pressures were used. In the Gascoyne and west Gascoyne, virtually all productive areas had been stocked long before the 1930s (Fyfe 1940, Williams *et al.* 1980). Furthermore, the average stocking rates in these areas (particularly within grazing radius of water) were known to be very high (Chapter 2.4).

The relative effect of the 1935–1940 drought was worse under HIGH stocking (population declined 80% between 1935 and 1947) than under LOW stocking (48% decline). However, in absolute terms the effect of the drought was worse under LOW stocking (reduction in density of 578 plants per ha) compared to that under HIGH stocking (reduction in density of 176 plants per ha).

The model indicated that under HIGH stocking, populations of 'desirable' shrubs had almost completely disappeared from the mid 1940s, without subsequent recovery. In support of this suggestion, we note that Wilcox (1979) presented data from one rangeland type in the Gascoyne on which palatable shrub densities ranged from 1,400 per ha when in good condition to nil when in poor condition. If indeed, many shrub populations in many areas had declined to extremely low densities (or even local extinction) by the mid 1940s then it is likely that few, if any, current managers would remember them and there would be some level of debate over whether or not they had even existed at high densities. This is borne out by the fact that dispute over whether or not various rangeland types had ever contained high densities of 'desirable' shrubs provided much of the vigorous debate following the release of the Gascoyne survey report (Wilcox and McKinnon 1972).

The average annual population growth rate using many random sequences was approximately equivalent to that obtained using the specific sequence of year-types over the last hundred years for both HIGH and LOW stocking rates. Thus, the simulation results suggest that the unique sequence of year-types encountered during the history of pastoralism did not produce a different outcome than the average of a random sequence of years using the same proportion of year-types (Table 3.2).

Learning from history – could 21st century knowledge have prevented the land degradation in the 20th century?

Had the shrublands been stocked conservatively from the outset, the simulation results suggest that resource degradation would not have occurred to the extent that it did. Estimates of carrying capacity for Western Australia's shrublands by both government and pastoralists were overly optimistic in the first fifty to seventy years of pastoralism. For example, Williams *et al.* (1980) estimated that by 1900 the number of sheep was already 60% of the peak level attained by 1934 and the leasehold conditions set by government included a commitment to stock at the rate of one sheep to 13.5 ha (following the first seven years of leasehold) averaged across the lease, but necessarily on few waters in the early years. This resulted in extremely high stocking rates in some areas.

Whether conservative stocking rates would have allowed the short- to medium-term financial ability to develop and maintain a pastoral industry was not determined in this study. Nevertheless, these models provide a basis for assessing the resource implications of policy.

The simulation studies also addressed whether more tactical approaches to annual stocking rate decisions could reduce the decline in shrub density. When a sensitive (SHORT ≥ 20%) management trigger was used to lighten stocking rate, the average annual population growth rate was 0.989 (Table 3.2). When a less-sensitive management trigger was used (SHORT ≥ 50%) the average APGR was 0.964. Using an insensitive indicator caused a decline in shrub density to extremely low levels.

Having prior knowledge of impending seasonal conditions did not prevent resource degradation when compared to strategies responding to resource condition (Table 3.2 and Figure 3.2). Using a default HIGH stocking rate and reducing stock only in Dry-Effect years (i.e. Perfect knowledge–heavy stocker) produced a long-term outcome similar to both constant HIGH stocking and the Responsive–insensitive strategy. Using a default LOW stocking rate and stocking only heavily in Wet-Effect years (i.e. Perfect knowledge–'conservative') produced a similar outcome to the Responsive–sensitive strategy.

Thus, perfect knowledge of impending seasonal conditions was not necessary to prevent resource degradation in the model, although it would undeniably be useful in practice. Using a sensitive biological indicator gave similar protection to the resource, and hence the most important message was that in both strategies (i.e. Responsive–sensitive and Perfect knowledge–conservative), a specific decision was made to lighten stocking rates rather than persist with high stocking rates at inappropriate times. Such a strategy also appears justified on an economic basis. Stafford Smith and Foran (1992) showed that substantial destocking in drought years had a better long-term expected economic return than a policy of 'hopeful inaction'. This result held true over a wide range of market conditions. The decision to destock was best made early in drought, which in the case of their study area was immediately following a failed winter season. This is true also for the Gascoyne, since summer seasons with effective rainfall are irregular and infrequent. Choosing to maintain stock numbers following a poor winter season represents a gamble that effective summer rainfall will follow, when in fact it has a low probability of occurrence.

Decadal scale climatic conditions

In the Gascoyne, four quasi-decadal scale periods can be identified that produced consistent medium- to long-term trends in shrub populations, based on simulation results from the constant LOW stocking rate (Figure 3.2). From 1891 to 1899 the population declined, followed by a generally upward trend until 1935. This was followed by a period of rapid downward trend until 1947. Since then, populations have fluctuated slightly but have been generally in decline. Altering the proportion of year-types used in the simulation would alter the average slopes of these four periods and may shift the post-1947 downward trend to a zero slope or slight increase. The general result would not change; conditions from the mid to late 1940s to the early 1990s were not conducive to a large increase in population. While it is too early to tell, the period from the mid 1990s may represent a fifth period, consisting of a general increase in density.

3.3.2 North East District, South Australia

The South Australian simulation suggested that at a constant LOW stocking rate, a period of sustained and severe reduction in shrub populations occurred from 1922 to 1949 (Figure 3.3 and Plate 3.1). The total reduction in density was approximately 65%. Although there were several subsequent periods of shrub decline (1959–1967 and 1976–1988) the general trend has been for an increase in population under constant LOW stocking rate since the low point in 1949, although the photo sequence from 1943, 1976 and 1995 (Plate 3.2) suggests that most of the recovery occurred in the last 25 years or so. Prior to the severe decline in the 1920s, the population had decreased from the time of settlement in the early 1890s until 1910 and had generally increased over the period 1911 to 1921.

Under constant HIGH stocking, the shrub population declined rapidly and almost linearly since settlement, so that by the time of the severe drought (late 1920s under LOW stocking) the population had already declined by 70%. Had a conservative manager had perfect knowledge of impending seasonal conditions (Perfect Knowledge – conservative) the outcome would have been marginally better than a manager simply reducing stocking rate on the basis of a sensitive biological indicator, i.e. SHORT stage ≥ 20% of the population. (Responsive – sensitive, Figure 3.3).

Plate 3.1 Drought has caused almost complete defoliation of saltbush in this example from North East District, South Australia. In some places, recovery took many decades. In other places, recovery did not occur. The photo was taken by Cecil Goode, Inspector of Pastoral Leases in South Australia in May 1944 and is part of the 'Historic Collection of the Pastoral Board of South Australia'. It was kindly provided by John McDonald, SA Department of Water, Land and Biodiversity Conservation.

a

b

c

Plate 3.2 This photo sequence shows improvements in a chenopod shrubland between Yunta and Olary over 52 years. Almost completely denuded in 1943 (Photo a), the site shows limited improvement by 1976 (Photo b) and a large increase in abundance and cover of chenopods by 1995 (Photo c). The 1943 photo was taken by Cecil Goode (Inspector of Pastoral Leases in South Australia), the 1976 photo by Gary Drewien and the 1995 photo by John McDonald. They are part of the 'Historic Collection of the Pastoral Board of South Australia' and were kindly provided by John McDonald, SA Department of Water, Land and Biodiversity Conservation.

The final outcomes for the South Australian simulation were almost identical to those from Western Australia, because the proportion of year-types and parameter sets were identical for the two areas. Thus, this allows for a comparison of the pattern and timing of change between the two locations but does not allow a comparison of the magnitude of change.

Some long-term data with which to compare the model output are available from the Koonamore Vegetation Reserve (KVR) (Hall *et al.* 1964). The KVR was fenced to exclude domestic stock in 1925 and shrub dynamics have been monitored at various intervals ever since. Many of the species reported by Hall *et al.* (1964) showed an increase in population from 1930 onwards. These include *Senna* spp. (Figures 9, 14 and 18 in Hall *et al.* 1964), *Atriplex vesicaria* and *A. stipitata* (Figures 9, 11, 12 and 14), and *Myoporum platycarpum, Santalum acuminatum, Acacia aneura, A. burkittii* (Figure 18). Other populations showed a general decrease over time such as *Myoporum platycarpum* (Figures 9 and 16). However, it is extremely difficult to make a general statement regarding comparisons between the model output and the data from Koonamore. The KVR was established on an area of overgrazed land in 1925 and it is likely that much of the rapid increase in populations on many of the transects was due to the exclosure from grazing and this has confounded the seasonal effect. This is particularly the case for short-lived species such as *Atriplex* spp. and *Senna* spp. There was also wide variation in population dynamics between transects and photo-points within the exclosure. This variation occurred within species as well as between species. Many of the populations on each transect were relatively small (<50 individuals). In these cases, demographic stochasticity is high and populations can be expected to fluctuate. Determining which of the sampled populations to use for model comparison is not obvious. For a more detailed study, the pooling of individual populations (for each species) to produce an average response for the KVR would dampen the effects of demographic stochasticity. This could then be used to compare with model output or could be used to develop a more sophisticated model than WALTER for the modelling of long-term dynamics.

As previously indicated in Chapter 2, Episode 2, McDonald and Lay (2002) found generally improved rangeland conditions over the last six decades, based on data from 53 photo-points and an additional 45 opportunistic observations. Original photos from the period 1943 to 1967 were compared with the same location during an on-ground visit from 1995 to 1998. While 28 of 53 sites maintained original structural form, many of the remaining sites changed from herbland/annual grassland or bare areas to shrublands. The sequence shown in Plate 3.2 is typical of this transition. Much of this change was accounted for by the increased cover component, from greater cover-abundance and increase in species number. Cover of low shrubs, especially chenopods, showed particular increases. Of the 32 species recorded, 23 increased in abundance and six decreased. In this environment, the most common species are chenopods, several of which displayed substantial increases in varied environments.

3.4 The IMAGES model – outputs and discussion

Simulation with the IMAGES model provided an independent assessment of the interaction of climate variability and grazing intensity (light and heavy stocking).

3.4.1 Gascoyne, Western Australia

Even under light stocking, the drought of 1935 to 1940 caused a decline in population of close to 50% by the end of 1942 (Figure 3.4). The population subsequently recovered by 1950. The only other drought sufficient to cause substantial decline in shrub populations under light stocking began in 1901. The population declined by about 25% (1905) and had recovered by 1912. The rainfall for this early period was taken from a station that had good daily records close to Carnarvon, on the Gascoyne coast. Hence the timing of this drought does not coincide with the 1890s drought or the 1912 drought in the Gascoyne. However, the

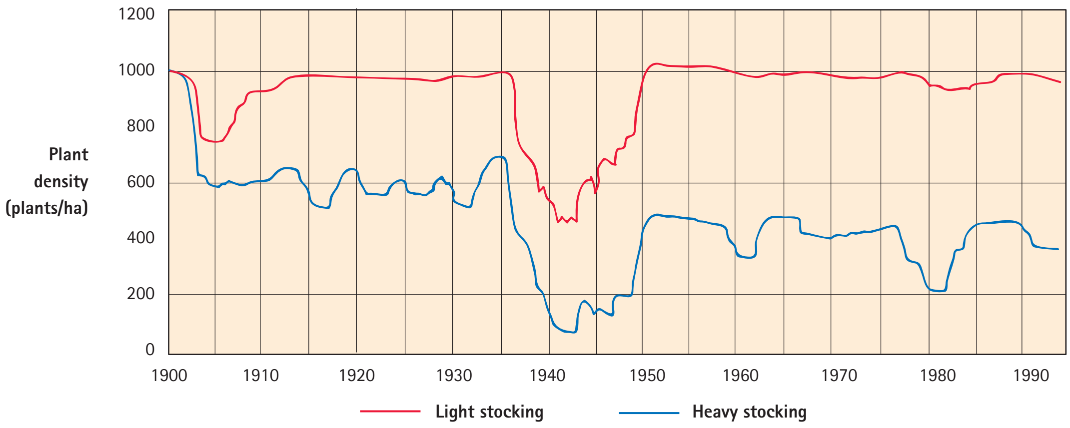

Figure 3.4. IMAGES model runs for north-west Gascoyne site, Western Australia.

timing is of less relevance than the fact that a severe drought occurred around the turn of the century and contributed to the decline in shrub density under heavy stocking before the major drought episode of the 1930s.

Only two droughts caused a substantial decline in the modelled population under light stocking. Even the drought at the end of the 1970s did not have much effect despite its appearance at the time (Plate 3.3). However, under heavy stocking the population was much more dynamic. The drought at the turn of the century decreased the population by 40%, with the drought of 1912 to 1914 reducing the population by 20% (from its post-1906 state), recovering by 1919. The severe drought of 1935 to 1940 reduced the population by 90%, with recovery to the post-1947 state not occurring until 1951. Subsequent droughts at the end of the 1950s and in 1976-80 also caused declines in the population.

3.4.2 North East District, South Australia

A drought ending in 1902 caused a decline in population of approximately 30% under light grazing (Figure 3.5). Under heavy grazing, the decline began two years previously, with the population falling by about 50% over four years. Following the recovery from drought in about 1908, populations under both grazing regimes (but more so under heavy grazing) generally declined until the next severe drought was encountered at the end of the 1920s. During this period (1908 to 1929) the population under heavy grazing was also affected by a dry period beginning in 1914.

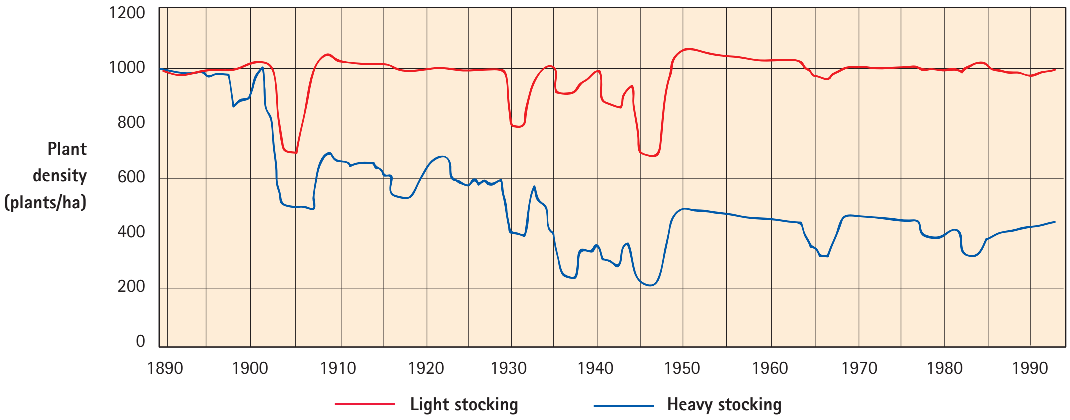

Figure 3.5. IMAGES model runs for the North East District, South Australia.

The drought beginning at the end of the 1920s was severe and protracted. Under light grazing there were several periods of recovery, but by the summer of 1946/47 the population had declined by about 30%. Under heavy grazing, the population declined by 65% from a maximum in 1922 to a minimum in 1947. Several subsequent droughts (late 1960s and mid 1980s) had an effect under heavy grazing but had little long-term effect under light grazing (Figure 3.5).

3.5 Summary of modelling of climate and management effects

The simulations from both models highlighted the deleterious impact of high stock numbers and intermittent drought periods on the loss of shrubs. The decline in shrub density was reduced by conservative stocking or responsive stocking decisions that reduced grazing pressure on shrubs in critical years.

The simulation studies support the view that, for Episodes 2 (South Australia) and 3 (Gascoyne, Western Australia) as described in Chapter 2 the severe drought periods both revealed and amplified previous degradation. The simulations suggest, with the benefit of hindsight, much of the loss of shrubs and resulting soil loss was avoidable.

The following section describes the remarkable increase in shrub density in the 1990s and early 2000s in the shrublands of Western Australia in association with well above-average rainfall for the last five to ten years. This has provided an opportunity to demonstrate that rangeland managers have learnt from history.

3.6 Epilogue 2001: A once in a lifetime opportunity in the southern rangelands of Western Australia

This section provides a case study of the interaction between history, science, monitoring and management. We have only anecdotal notes to tell the history of vegetation changes during the entire period of pastoralism so a modelling approach was used in this chapter to simulate shrub density over the last century. The modelling is plausible but we lack the historical data to evaluate how accurately it portrays the timing and extent of change. Ideally, a monitoring system is necessary to record this change, consisting of repeatable, objective assessments of the resource over many years. Since the early 1990s, the Western Australian Rangeland Monitoring System (WARMS) has performed this function in the Gascoyne and throughout the pastoral rangelands of Western Australia (Watson *et al.* 2001).

As indicated in Chapter 1 and Fig 3.1, the Gascoyne region experienced rainfall during the 1990s (1991 to 2000) greater than any similar period in the 114 year historical record. WARMS was able to document the changes during the latter part of this period and these provided independent validation to the modelling and also provided some direct feedback to individual land managers and to government. In turn, what we had learnt from compiling the history of the degradation episode had an impact on the way we provided the monitoring results to the pastoral industry in the southern rangelands of Western Australia.

The following is an edited version of a Pastoral Memo Southern Rangelands article by one of the authors (Watson 2001). The Pastoral Memo is the primary written communication vehicle between the Department of Agriculture Western Australia and the pastoral industry. When the article was written, the WARMS analysis was still in draft. Therefore, the text below has been amended to reflect this and includes some text from a separate article (Watson and Thomas 2003) that details the final analysis.

> Pastoral managers across the Southern Rangelands have been presented with a rare opportunity to capitalise on improvements in the rangelands. The challenge is not to let this opportunity slip by.

a

Plate 3.3 Photo-pairs from the Gascoyne, photographed in April 1980, at the end of the 1976-80 drought (Photos a and c) and again in August 2000 (Photos b and d). Despite this drought being considered severe at the time, and the obvious drought effects in the 1980 photos, the modelling suggests that the 1976-80 drought was far less severe than some previous droughts, particularly that of the late 1930s and early 1940s.

Photos: a, c from Richard Allen and Alec Holm, 1980; b, d from John Stretch, 2000, Department of Agriculture Western Australia

b

Preliminary assessment of the latest WARMS data from Southern Rangelands sites suggests that in the last 6 or 7 years some extraordinary changes have occurred.

- Perennial vegetation cover has almost doubled on average.
- There has been much shrub recruitment across a wide range of species.
- Species richness has been maintained or increased on most sites.
- Shrub density increased on most sites.
- The only 'crashes' in populations came from sites we know to have been flood damaged.

The consistency of these results for many species, most sites and across all parts of the Southern Rangelands is simply remarkable.

I am starting to come to the conclusion that this is at least a once in a lifetime event and possibly even a once in **several** lifetimes event. On its own, this event has the potential to redress at least some of the degradation that has occurred in the past and may even be able to lift the rangelands to a different level of stability. The challenge for managers now is to grasp this opportunity and ensure that the gains are not lost as soon as the seasons turn dry again.

Plate 3.3 Continued

c

d

Why get so excited about a few shrubs?

Perennial vegetation (both shrubs and grasses) tells us much about the health of the rangelands. The composition, abundance and vigour of the perennials provide an important indication of the health of the landscape for pastoral production. Perennial vegetation regulates the flow of water and nutrients across the landscape and while some perennial species are regarded as undesirable (i.e. woody weeds), the general rule is that more perennials are better than less perennials as they reduce the loss of soil and water resources from the system.

For those of you who like to see the statistics behind the generalities, here is some detail from the 223 sites (38,359 plants!) from the Gascoyne-Murchison area I've been working on recently, although the story is the same throughout the region. The sites were all installed between the end of 1993 and the beginning of 1997 and reassessed between mid 1999 and mid 2001.

- The average increase in canopy area for each site was 81%, with only 8 of 223 sites showing a decrease.
- Almost 90% of individual shrubs stayed the same size, or increased in size. These two results suggest that the shrubs are robust and healthy.
- When considering all populations of shrubs, including those with only a few individuals of a particular species, seedlings were found for 81% of species, within 67% of populations.

> - When considering populations in which there were at least 20 individuals on the site (i.e. populations of sufficient size to reasonably expect recruitment), seedlings were found for 96% of species, within 94% of populations. These results suggest that shrub populations are regenerating, beyond expectations in many cases.
> - The number of different species on each site remained constant or increased on 91% of sites, suggesting species richness is being maintained or improved.
> - The average increase in shrub density was close to 50%, with 26 sites more than doubling in density between visits and only 23 sites showing a decrease.
> - When considering only those long-lived species, which are the hardest to replace, shrub density increased on 80% of sites. In simple terms, more shrubs are being recruited to the population than are dying. So not only are the individual plants in good shape, but the populations themselves are in good shape.
>
> WARMS sites are designed to be representative of the bulk of the landscape. So these results don't necessarily mean that all the rangelands are improving since there will still be situations, such as gully heads and scalded floodplains, where erosion continues. However, the numbers from the WARMS sites are irrefutable and the story they tell is very good.
>
> Teasing out the relative effects of season and management causing this improvement is much more difficult. Certainly, the general sequence of seasons over the last few years was better than most people can remember. However, pastoral management has become more benign over the last few decades and some improvement in perennial vegetation would be expected. It may be that this relatively wet period allowed those management gains to be expressed. That is, that improved management over time conditioned the rangelands to respond. Good rainfall triggered this response. Whatever the reasons, the challenge now is to maintain this improvement and not let the rangelands slip back as soon as it gets dry again.
>
> It is not for me to prescribe how the land should be managed to maintain the improvement; that is best left to the manager on the ground. However, the key principle is matching animal numbers to land capability and feed availability; managing total grazing pressure and making sure that animal numbers are reduced quickly and sufficiently when going into a dry period.
>
> History suggests that while some of the major productivity improvements occurred during sequences of good seasons, some of the biggest degradation events occurred immediately after them while animal numbers were still high and managers had come to expect that good seasons were now the 'norm'. It is important that the mistakes of the past are not repeated. These days, most managers have a much better understanding of the climatic variability they work within, improved road transport means that animals can be shifted more easily and most importantly, the general conservation ethic is much more sophisticated than it has ever been.
>
> But without wanting to labour the point …
>
> If we miss this opportunity, we may have to wait a **very** long time for another to present itself.

The above-average rainfall period finished abruptly, with many stations receiving their last substantial rainfall event in March 2000. Rainfall since then has been low, with failures throughout much of the Gascoyne – Murchison in successive winters of 2000, 2001, 2002 and 2003. In July 2003, an Exceptional Circumstances declaration was made by the Commonwealth Government for drought assistance over much of the Southern Rangelands, including most of the Gascoyne-Murchison area. This declaration was based on the failure of the 2001 and 2002 seasons. So, while the wet period provided an exceptional opportunity for resource recovery, the ensuing dry period will provide a test of the extent to which managers have learnt from the past and adjusted stock numbers to reduce the risk of degradation.

Chapter 4

Analysis of grazing pressure from the long-term livestock records of two western Queensland pastoral properties

G.S. STONE

4.1 Introduction

The condition of the pasture resource of a property is the result of an individual grazier's decisions on the management of livestock numbers and other herbivores (e.g. rabbits, goats and macropods) in response to climate variability. Hence individual property records, which include events involving livestock management, along with rainfall records, are the fundamental information required for reconstructing pastoral history and events of ecological significance (Oxley 1987a, Pickard 1990, Landsberg *et al.* 1998). I present in this chapter case studies of the development and analysis of climate and livestock management records for two western Queensland properties. In particular, I concentrate on the accounting and flow of annual livestock numbers (sheep, cattle and horses) for the purposes of estimating grazing pressure of domestic livestock.

Annual livestock records represent one of the most personal and private components of a grazier's life. For this reason there are understandably relatively few long-term records published. Nevertheless, detailed livestock records provide the statistical data that will allow other graziers and resource managers to analyse past success and failure, and plan for better management in the future. From the 1960s the Department of Primary Industries has established major research and extension centres in western Queensland concentrating on rangeland management. This chapter in detailing the observations of graziers provides additional information to the repository of extensive scientific and extension material. My purpose in presenting the following case studies is to stimulate other graziers to document their records for future generations of pasture managers.

The properties are located on two widespread and important pasture communities in western Queensland: Mitchell grasslands (Lansdowne station, Tambo, Figure 4.1), and mulga woodlands (Moble station, Quilpie). Management records of both properties were available for extended time periods (Lansdowne 115 years, Moble 74 years) that enabled interaction between climate, pasture, management and economic factors to be analysed comprehensively (Figure 4.2).

The two properties are regarded as being in relatively good condition. Unfortunately for scientific comparison, records from properties in poor condition were not available. The difficulty of finding long-term property records was highlighted by the Warrego Graziers Association who sought property records for their 1988 report (p. 26):

> The committee set out with a list of six properties all less than 20,000 hectares. It was found that ownership of one of these blocks had changed four times in 3 years, the other blocks ranging from one sale every 3 years to once a year. The end result was that tenure has never been long enough to enable the gathering of figures that would show anything, let alone decline.

Property background and features

A number of features of the Lansdowne and Moble properties made them appealing propositions for reconstructing past histories. These include: a) continuous stock and rainfall records over a long period; and b) accurate property descriptions over time, as the present owners are family descendants or connected by business affiliation. Since both properties have derived their income primarily from wool, they have been subject to identical market forces (e.g. wool price collapses of 1925, 1929 and wool booms such as the 1950s) as well as similar broad climate sequences over time. Moble is located in a more arid region than Lansdowne (Table 4.1). Rainfall, measured at a single gauge (homestead location) has been highly variable from year-to-year for both locations with a coefficient of variation (CV) of 36% for Lansdowne and 52% for Moble. As soil, vegetation and type of country (e.g. open downs in contrast to woodlands) vary considerably between the two sites, contrasts exist regarding the response of the respective country to climate and management strategies.

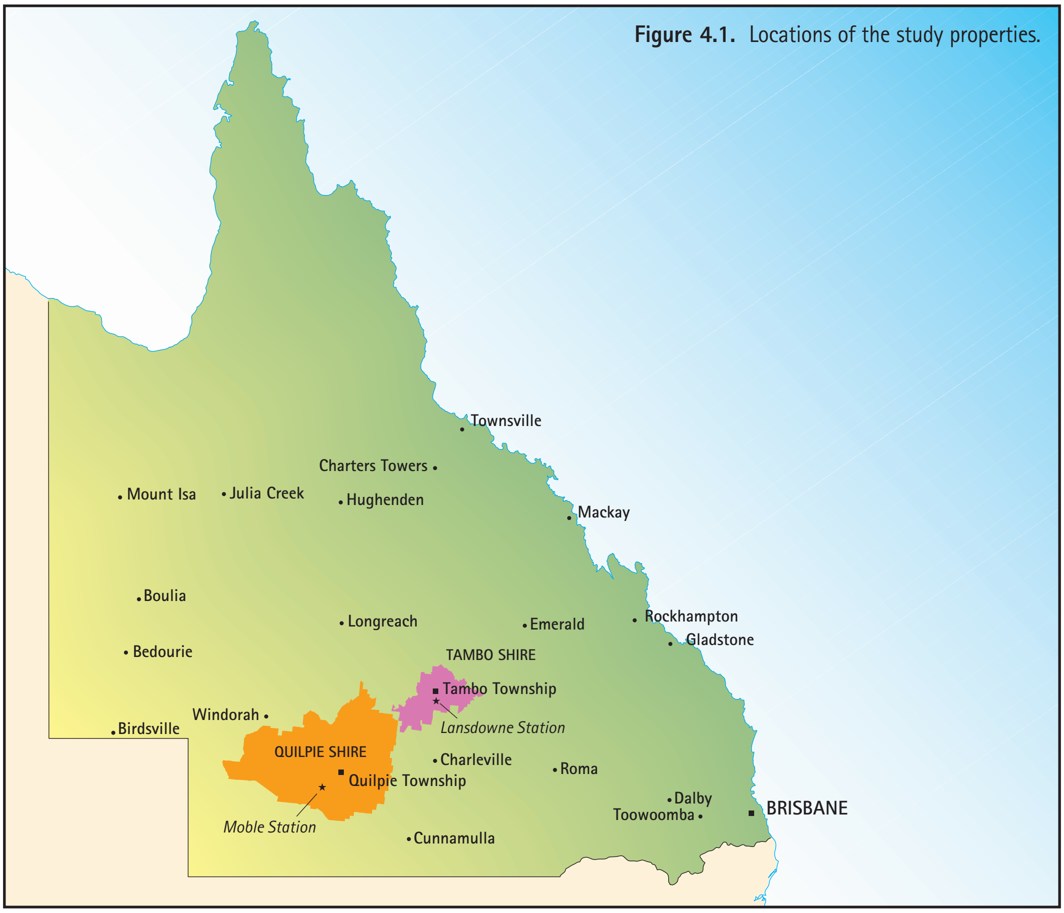

Figure 4.1. Locations of the study properties.

Calculations of stocking rate were based upon the total area of land holding that was available for grazing purposes. However, historical grazing pressure may be underestimated, especially in the period prior to major improvements and fencing of the respective properties (Sections 4.2.2 and 4.3.2) as these developments effectively increase the area that was actually grazed. Furthermore, data on numbers of macropods and feral herbivores (e.g. rabbits and goats) were not available at either the property or shire level and thus cannot be included in the calculation of grazing pressure.

There is insufficient information on the pastoral industry as a whole to comment on how well Lansdowne and Moble represent stations of the central and south-western districts of Queensland. They are, however, grazing

Table 4.1. Descriptive statistics of annual (January–December) rainfall for Lansdowne (Tambo shire) and Moble stations (Quilpie shire).

Rainfall statistic	Moble [1]	Lansdowne [2]	
	(1924–1997)	(1924–1997)[a]	(1880–1998)[b]
Median (mm)	288	486	483
Mean (mm)	316	496	515
Standard deviation (mm)	163	179	204
Coefficient of variation (%)	52	36	40
Maximum (mm)	778	1,216	1,327
Minimum (mm)	72	197	112

[1] actual annual rainfall (January-December) from Moble rainfall records.
[2a] actual rainfall (January-December),
[2b] actual rainfall data with missing data 'patched' using the 'SILO' Database (Mullen and Beswick 1998).

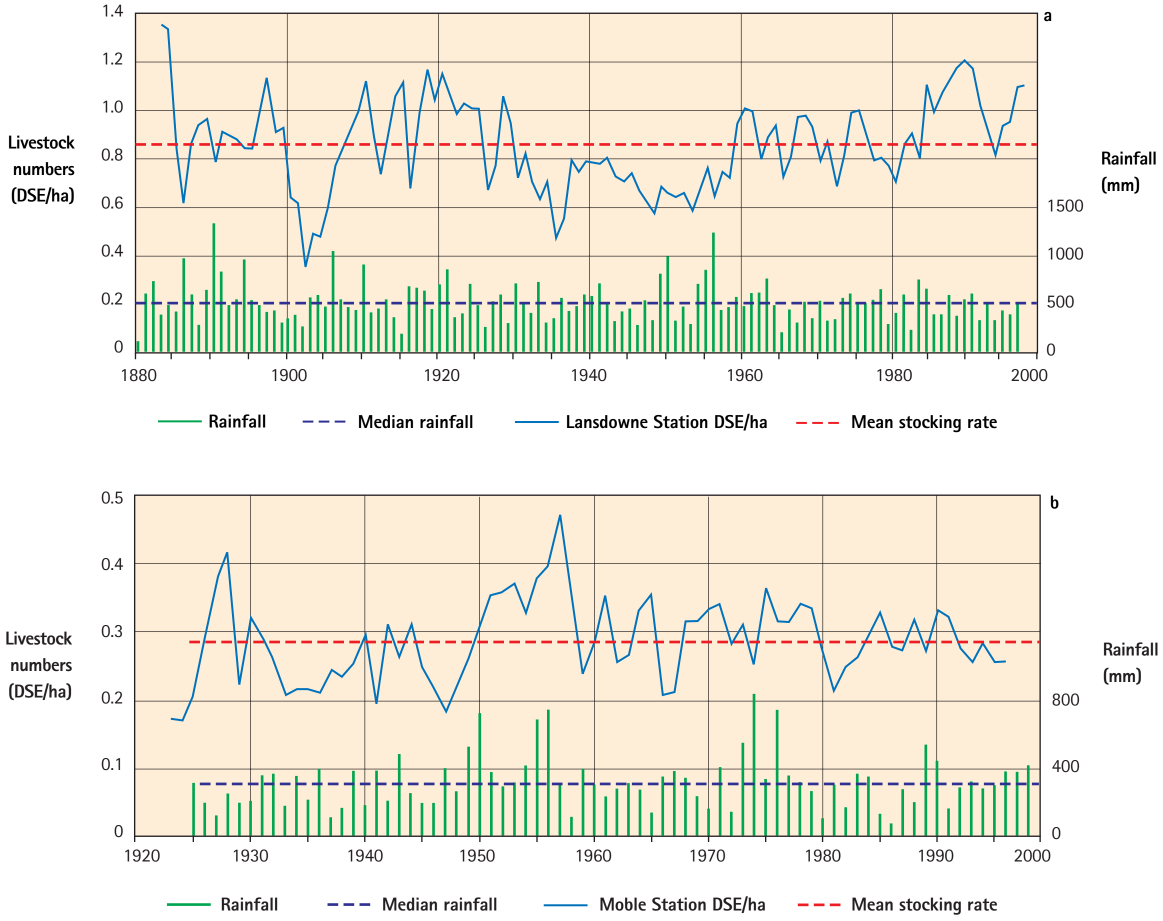

Figure 4.2 **a** Lansdowne livestock numbers, shown as dry sheep equivalents per hectare (DSE/ha), and annual (Jan.–Dec.) rainfall (mm); and **b** Moble livestock numbers (DSE/ha) and annual rainfall (Sep.–Aug.).

enterprises that have been under the same ownership and management regime for many decades, and have remained viable over that time. The fact that they are regarded as being in good condition (P. Johnston pers. comm., Garrad and Johnston 1998) after this length of time indicates successful financial and grazing management with respect to managing for climate variability and achieving long-term sustainability.

It should be noted that there is no intention to pass judgement using the benefit of hindsight on the historical management of the studied properties. However, it is hoped that the examination of selected events from the grazing history of the properties may illustrate how and why these enterprises hold their present position in Queensland's pastoral industry despite the highly variable climatic and economic environment of the last hundred years.

Sheep size and animal equivalents

Several animal studies have used a conversion factor of 7 dry sheep equivalents (DSE; 45 kg) per dry adult equivalent (AE), defined as a 450 kg cow or horse (Cooke–Yarborough 1990, Field and Cobon 1997). However, there is considerable variation in conversion factors in the literature (e.g. Pickard 1990) and lack of precision in terms of defining what is being converted to what. For example, Bureau of Agricultural Economics (1969), Daly (1994), Garrad and O'Shannessy (1997) and Miles (1989) considered 8 sheep to be equivalent to 1 AE.

Some previous studies and recent analyses of historical data have used 10 DSE/AE (Anon. 1914, Beadle 1948, Lawrence *et al.* 1991). The change from 10 DSE/AE to 7 suggests a potential change in sheep body size over time. Many records simply report head counts with no information on weight, size, sex or physiological status that precludes accurate calculation of total stocking rates for grazing pressure/utilisation calculation. Both the origin of this value (10 DSE/AE) and body weights of Queensland sheep at the turn of the century are largely unknown despite a comprehensive search of the literature. Historically, Queensland has had smaller sheep in contrast to other States. Most of the big shearing tallies by men such as Jack Howe (321 lambs in 7 hrs 40 mins, Muir 1993) were set in Queensland as the sheep were lighter and the wool less dense (Taylor 1988). In September 1895 at Barenya station (Hughenden), 26 shearers averaged 172 sheep each in one day, with 8 shearers averaging 236 each (Taylor 1988). The shearer's working 'day', however, may have varied across districts and time. Tallies for today's shearers generally range between 120–140 head per day.

One possible reason for the use of 10 DSE/AE as a conversion factor was the ease of calculation. For example, 10 DSE at 100 lb liveweight (≈45 kg) would have been roughly equivalent to one AE at a liveweight of 1,000 lb (≈450 kg). Another possible origin of the conversion factor may lie in historical statutes such as the *'rental rate of grazing animals'*, set by Lord Kimberley in the 1880s, presiding in England as Secretary of State for the Colonies (Durack 1968). The rate (10 shillings per 1,000 acres) was set for undeveloped blocks of land that were to stock at 20 sheep or two cattle (i.e. 10:1) for the nominated area or forfeit of the lease would result.

The increase in fleece weight of Australian Merinos over time has been well documented (e.g. Gramshaw and Lloyd 1993, Hall 1996). However, it is uncertain how much of this increase, especially in earlier periods, can be attributed to breeding or improvements in husbandry (Turner 1962). Assuming that selection for heavier fleece weight per animal has been responsible for a large proportion of the increase in fleece weights, it does not necessarily follow that this selection has had a secondary effect on body weight (BW). For example, a study by CSIRO (1954) over an eight–year period at Trangie and Cunnamulla found that clean fleece weight (CFW) increased by 1 lb (454 g) with respect to control animals following selection for CFW. However, BW of the selected and control animals did not differ significantly. Conversely, the same selection pressure upon strong wool strains (i.e. thicker in fibre diameter) at Roseworthy (South Australia) produced a strong positive correlation between CFW and BW (CSIRO 1954). The authors of this research concluded that selection for CFW may result in larger sheep size only for strong wool strains.

The Peppin strain of Merino has dominated the semi-arid areas of Queensland because of its suitability to the prevailing climate (Lilley 1973). However, importation of larger-framed strong wool sheep since the 1970s has potentially increased the size and live weight of the Queensland Merino, at least on individual properties in specific regions of the State (D. Cobon pers. comm.). However, assumption of such an impact throughout the Queensland flock could not be considered without further evidence.

The conversion of sheep and cattle numbers to a common unit is commonly done to estimate total feed intake (Cooke–Yarborough 1990, Hall 1996). However, this would not appear to be the basis for early conversions (10 DSE/AE) as described previously. In addition, given the evidence of negligible body weight change as a result of selection for fleece weight, this study will use the more accepted conversion factor of 7 DSE/AE for all analyses. Horse numbers were converted to DSE at the same rate (7 DSE) for the analysis, as the feed intake of the average work horse was considered to be similar to adult cattle (K. Dowsett pers. comm., K. Rickert pers. comm.).

A further assumption is that the change of adult cattle size over time has also been small if not negligible. This assumption has been made for the study properties alone since they have historically both had large sheep components and the cattle breeds have been consistently *Bos taurus* (Shorthorn). The question of quantifying cattle bodyweight over time is fraught with problems. For example, if slaughter data are to be used then aspects such as breed, sex, age, fat score, property origin, markets and seasonal pasture data must also be obtained in order to accurately convert carcass weight back to a live animal status.

Shire stock numbers

Statistical livestock numbers (e.g. Statistics of Queensland, ABS) for Tambo (1892–1993) and Quilpie (1952–1993) shires have been obtained and analysed in conjunction with aspects of the property data (e.g. Tables 4.4, 4.7). Both shires have a 'damped' effect (in terms of absolute changes in stock numbers) compared to the variability of the property data. This was to be expected given shire values aggregate data from properties which differ markedly in soils, pastures, livestock type and management (e.g. low and high 'stockers'). In addition to this, Daly (1994) noted that recorded sheep numbers appear to be more 'volatile' when compared to cattle numbers and yet, because shearing tallies were kept, probably have a high degree of accuracy and therefore give a true indication of seasonal trends.

A limitation of using shire data in the past has been the difference in the times when stock numbers are recorded (e.g. at shearing) and reported (Young and Miles 1982). For example, Lansdowne livestock numbers and Queensland statistics were recorded as at 31 December each year until 1941, when Queensland statistics were then reported as at 31 March. However, Young and Miles (1982) and Daly (1994) noted that although census livestock numbers were problematic, trends were still accurate. Another problem encountered for this analysis was the absence of statistics for 1941 and 1951 for Tambo shire. Livestock numbers for these missing years were obtained by taking the average of the year either side of the missing year.

It should also be noted that horse numbers were not obtained for either Tambo or Quilpie shires for the period 1952–1993. When horse numbers were removed from the total stocking rate calculations for either property, the effect was negligible.

4.2 Lansdowne Station

4.2.1 Property background and records

The Lansdowne Pastoral Company was established in 1881 by George Fairbairn and, as a publicly listed company, has since then made property and financial details known to shareholders. Such details and anecdotal property information were compiled into a book in 1973 entitled *Story of Lansdowne: The History of a Western Queensland Sheep Station* by G.W. Lilley who himself was a manager of Lansdowne for 20 years.

Property details such as livestock numbers, wool produced, dividends and rainfall up to the year 1971 have been extracted from Lilley's book. The current manager of Lansdowne, Mr Hume Turnbull, and the directors of Lansdowne Pastoral Company have kindly made monthly property reports available so that the time-series of livestock can be updated from 1971 onwards. The reports not only recorded all monthly livestock numbers, along with births and deaths, but also cumulative totals of sales and purchases for the year.

In addition, access was provided to a number of the company's annual reports. The annual reports included details of seasonal conditions, rainfall effects and feed abundance, time of management practices (e.g. shearing), need for agistment, supplementary and drought feeding, wool sold, bushfires, water conditions and property improvements. Historical anecdotes up to 1971 were also available from Lilley's book.

4.2.2 Property features

Lansdowne is a 62,205 ha sheep (primary) and cattle (secondary) property located on the Ward River, 21 km south of Tambo (Figure 4.1; property position: latitude 25.07° South, longitude 146.27° East; Plate 4.1). The property exists as two separate portions of land that are approximately eight kilometres apart. The two blocks are referred to as 'Upper' and 'Lower' Lansdowne.

Plate 4.1 Mitchell grass pasture (*Astrebla* spp.) is the well recognised grazing component predominantly found on Lansdowne. These examples of Mitchell grass downs are from the central-western Queensland region and represent much of the Lansdowne property.

Photo a shows Mitchell grass in a 'growth' phase regarded as highly nutritious to domestic livestock and other herbivores (e.g. kangaroos). Photo b displays the same pasture species in a non-growth 'hayed-off' phase, which is still very beneficial to livestock and hence its worth to the grazing industry.

Photos by Robert Hassett (Natural Resource Sciences, Queensland Department of Natural Resources, Mines and Energy).

The climate that governs soil, plant and animal processes is one of hot summers and cold winters. Maximum temperatures of 45°C have been recorded in summer, with winter lows dropping to –5°C. Frequent heavy frosts are a feature of the Tambo district in June and July (Lilley 1973, Orr and Holmes 1984).

Lansdowne's mean annual calendar rainfall (Table 4.1) was 515 mm for the period (1890–1998), while the median was only 483 mm. Lilley (1973) stated that summer rainfall included heavy falls but had the greatest variability, and that winter rainfall was more reliable in this area of central-western Queensland. However, an analysis of long-term (1880–1998) summer (September–March) and winter (April–August) rainfall showed that winter rainfall (CV = 69%) actually has a higher variability than summer rainfall (CV = 44%). Winter rainfall also comprises only 29% of Lansdowne's long-term annual rainfall. High variability exists for rainfall in each month (Figure 4.3 and Table 4.2), with greater variability in winter months.

Property area

Areas of Lansdowne were selected from 1861 through to 1863, when the holdings peaked at 204,351 ha (Table 4.3). A series of lease lapses, resumptions and freeholdings followed initial selection to reduce Lansdowne to its present size, now comprising 48,040 ha freehold, 14,164 ha leasehold, 240 ha water reserve and an additional 3 ha stock water point.

Table 4.2 Coefficient of variation for Lansdowne monthly rainfall for 1880 – 1998.

Month	Coefficient of Variation (%)	Month	Coefficient of Variation (%)
January	86.2	July	129.5
February	92.6	August	127.5
March	113.9	September	138.8
April	137.0	October	95.9
May	116.9	November	92.2
June	111.0	December	81.5

Land type and vegetation

Lilley (1973, p. 29–30) described Lansdowne country as:

> heavily-grassed open downs, timbered on the creeks and lighter soil ridges. The soil on the downs is brown to grey with a depth of from three to five feet, with an underlying yellow shale. On the ridges it is a lighter brown soil interspersed with sandstone. Claypans occur frequently along creeks and gullies, providing valuable run-off areas for excavated tanks. In dry periods the grey soils develop deep cracks.

The important pasture species on Lansdowne, with respect to grazing animals are: Mitchell grass (*Astrebla* spp.), Queensland blue grass (*Dichanthium sericeum*), buffel grass (*Cenchrus ciliaris*) and Flinders grass (*Iseilema* spp.). Mitchell grass forms the bulk of the pasture (Plate 4.1). The exotic buffel grass has at times encroached on the extensive Mitchell grass areas of Lansdowne and currently covers less than five percent of the property. It is confined mainly to stock waters and camps as well as the higher ridge country where the soil depth is shallow and usually red in colour (H. Turnbull pers. comm.). Wire grasses, e.g. feathertop (*Aristida latifolia*) and white speargrass (*Aristida leptopoda*) are the most important 'weed' species present on Lansdowne, due to their ability to cause 'shive' (plant matter) in fleeces and reduction in fleece values.

The major tree communities on Lansdowne comprise brigalow (*Acacia harpophylla*), gidyea (*Acacia cambagei*), myall (*Acacia pendula*), coolibah (*Eucalyptus microtheca*) with other scattered *Eucalyptus* spp. These communities, however, do not encompass large areas on the property.

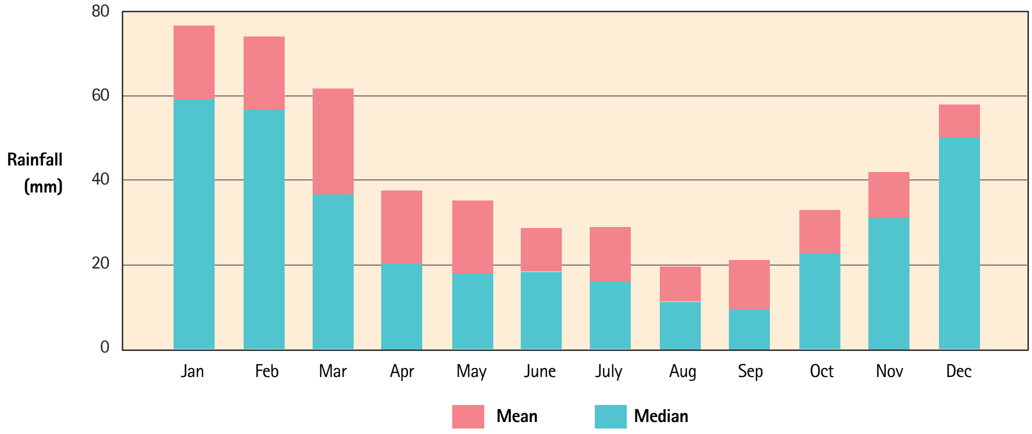

Figure 4.3. Mean and median monthly rainfall of Lansdowne for the period 1880-1998.
Source: Actual and patched rainfall (Mullen and Beswick 1998).

Table 4.3. Lansdowne landholdings and changes.

Date	Details	Resumptions (ha)	Leasehold area (ha)	Freehold area (ha)	Total area (ha)
1861	selection	–	152,292	–	152,292
1863	selection	–	204,351	–	204,351
1876	lapse of leases	–	174,437	–	174,437
1881	change of leases	–	176,121	25,900	202,021
1886–1892	resumption	26,773	149,348	25,900	175,248
1884–1896	resumption	59,992	89,356	25,900	115,256
1903[1]	freeholding	–	64,750	48,043	112,793
1914[2]	resumption	16,317	48,433	48,043	96,476
1934[3]	resumption	16,900	31,145	48,043	79,188
1946	water point excised	3	31,145	48,040	79,185
1949	resumption	16,981	14,164	48,040	62,205

[1] total area after freeholding (112 793 ha) stated in Lilley (1973) gives a shortfall of 2 463 ha from previous mentioned total area (115 256 ha).

[2] to arrive at 48 433 ha, the area retained as stated by Lilley (1973), the area resumed must have been 16 317 ha, not 16 188 ha.

[3] loss in 1934 gives 79 576 ha not 79 188 ha, as stated in Lilley (1973).

Pest animals

A number of animals have at times been a concern to property management on Lansdowne, often causing a reduction in livestock production (Lilley 1973).

Kangaroos are the dominant native grazers. The red or 'blue' kangaroo (Lilley 1973) has been the most numerous until recent years, whereas the grey or 'forester' is now considered predominant. Macropods provide the most competition for domestic stock and consequently should be ideally taken into consideration when calculating 'total grazing pressure'.

The open downs country of Lansdowne and surrounding properties is not wholly suitable to dingoes with dog-netting fences helping to keep numbers under control. It is an increasing observation in this area that wild dogs and dingo crosses are responsible for the majority of livestock attacks.

Feral pigs are considered a major pest, with numbers difficult to control. Bore drains and fences are often damaged, with losses of lambs and weak sheep a common occurrence. The fox is the other introduced species that has a large impact on lamb numbers and other native fauna (e.g. plain turkeys).

Rabbits were not considered a problem on Lansdowne in the past, as the heavy downs soils do not provide an ideal medium for warrens. They are present, however, and the population is said to be kept in check by native (goannas) and introduced (foxes) predators.

Indications of property condition

Lansdowne has recently taken part in the government-funded project, *Appraising safe carrying capacities for all properties in South West Queensland* (Garrad and Johnston 1998) with an assessment that the property was in fair to good condition with respect to the pasture and the land resource as a whole (P. Johnston pers. comm.). The Mitchell grasslands in general are often considered to be resilient despite the effects of both drought and continuous grazing by livestock (e.g. Orr and Holmes 1984).

Lansdowne was recognised even from early times as being highly productive country. In 1903 the land court sitting at Tambo apportioned the highest rental of the Blackall and Tambo runs to Lansdowne (Lilley 1973), indicating that the Lansdowne holdings represented superior country.

A number of periods throughout Lansdowne's history reflect dramatic fluctuations in stock numbers, largely as a result of climate variability (Figure 4.2a). It is noteworthy that after such periods of drought, pastures were able to support rapid increases in stock numbers, often returning to pre-drought stocking rates within two years. Such events help substantiate statements of how resilient the downs country is over time.

Improvements – water and fencing

Fencing on Lansdowne did not begin until the 1870s with sheep being shepherded prior to this. The range of grazing available to stock was restricted to country adjacent to permanent and semi-permanent waterholes, as no water conservation had yet begun. This left large areas of country not grazed by domestic livestock except in exceptional seasons when water could be found in gilgais. The terms of the lease at this time required a stocking rate of 25 sheep to the square mile (1 sheep per 10 ha or 0.1 DSE/ha).

The first attempts at water conservation were excavations and weir-like structures located in creeks, their longevity depending on the force and frequency of flows. Ring tanks were then tried on smaller creeks and gullies. The first artesian bore was sunk in 1889, two years after artesian water was first discovered on Thurulgoona station in south-western Queensland (Oxley 1987a). Subsequent bores established in 1892, 1896, 1911 and 1915 yielded good quality domestic and stock water, with brackish sub-artesian water found in 1911 and 1912. By the 1930s bore flows had diminished to a point where alternative sources of stockwater such as earth tanks were established. The absorptive nature of the heavy downs country restricted construction to claypan run-off areas where the catchment was guaranteed and less silt was carried into the tank.

A large-scale program of property subdivision commenced in 1951, including establishment of a further 10 ring tanks, with the aim of increasing the area of land routinely available to grazing. These improvements led to Lansdowne being well serviced with watering facilities and thus enhanced livestock production and decreased drought susceptibility.

4.2.3 Stock numbers

Lansdowne has maintained sheep as the predominant domestic grazing animal for most of its history. Holmes (1983) found, in a survey over the period 1972–1981, that economic returns were higher from sheep in the central and southern grasslands (e.g. Blackall, Tambo and Cunnamulla) and declined along a gradient towards Julia Creek. This gradient was associated with lower reproduction rates and large periodic losses of sheep through climatically related events such as fire, flood and fly waves.

A variable number of shorthorn cattle (range 50–517 head) were depastured for 78 years until 1961 when the maximum number of breeders was increased to 1,000. In 1967 the ceiling was raised to 4,000 breeders, with modifications initiated to the property to cater for the additional cattle numbers including fencing, waters and management practices. However, this figure was never reached and breeder numbers remained below 1500 head (H. Turnbull pers. comm.).

Over a 115–year period the average stocking rate (DSEs divided by property area at the time) for Lansdowne was 0.86 DSE/ha (Table 4.4), with a maximum and minimum value of 1.36 DSE/ha (1883) and 0.36 DSE/ha (1902) respectively.

Time of stock number recording

Livestock numbers, as reported by Lilley (1973), were from the December monthly reports. Similarly, from 1971 onwards stock numbers were also taken from the company's December monthly reports. The time-series was therefore confined to one time of the year, and the period when sheep numbers were likely to be at the lowest point for the year (Pickard 1990, H. Turnbull pers. comm.). The most probable time of year when sheep numbers peaked was at shearing (November), with sales usually taking place after this.

Table 4.4 Descriptive statistics of stocking rate for Lansdowne and Tambo shire.

Statistic	Lansdowne		Tambo shire
	(1883–1997) [a]	(1892–1993) [b]	(1892–1993)
Mean (DSE/ha)	0.86	0.84	0.56
Standard deviation (DSE/ha)	0.19	0.18	0.13
Coefficient of variation (%)	22	21	23
Maximum (DSE/ha)	1.36	1.21	0.83
Minimum (DSE/ha)	0.36	0.36	0.23

[a] Includes total record period for Lansdowne
[b] Includes same record period as Tambo shire statistics

Timing of management activities

Livestock management is generally constrained by climate. Events such as shearing, lamb marking, joining and weaning are timed to take advantage of the within-year climate variation. Shearing of the main commercial flock on Lansdowne now takes place around October but has varied in the past to be as late as February (e.g. 1983) (information taken from Lansdowne Pastoral Company Limited annual reports, various issues). The stud flock is currently shorn in April–May. Shearing and lambing dates have been altered over time to suit changes in livestock management. Joining of stud and flock ewes takes place in March–May and November–December respectively. The main sheep dispersal sale is held in March while paddock sales of commercial rams take place throughout the year.

Older cows at Lansdowne are usually joined in late December, while the heifers are joined earlier at the start of December. Time of joining, however, still depends on breeder condition, feed availability and storm rain. Calving occurs from September onwards with the intention that breeders support their offspring on late winter standover feed and early summer pasture growth. Branding and weaning occurs around April–May. Generally for a cow to have a calf each year, she must recover sufficient body condition post-weaning (May) to support a new calf (September) and conceive again two months later in December. While this is the ideal objective, it is seldom achieved due mainly to the considerable climatic variation. Sales are not restricted to a specific time of the year with cattle being preferably sold for slaughter.

4.2.4 Land resumptions

Table 4.3 shows how the large tract of land initially selected as Lansdowne was reduced over time to less than a third of its original size. In today's terms Lansdowne is still a sizeable property with some justification to remain this way given the controversy associated with splitting small areas off large holdings (Lilley 1973, Anon. 1995). An example of this was in 1914 when an area of 16,200 ha was resumed to be selected as two 5,700 ha and one 4,800 ha blocks open for ballot. In the same period, subdivisions near Ilfracombe were to be set at just over 2,000 ha. Such small living areas were seen as an act of folly by the Lands Department of the period, even though the industry was buoyant at the time. Subsequently many of the leases expired or

were sold to amalgamate small holdings to become liveable areas (Lilley 1973). It has been well documented for a number of areas (Anon. 1993, Mills 1989, Passmore and Brown 1991), where property splits were part of government policy, that land and primary production have suffered due to the lack of management flexibility during periods of high climate variability compared to the potential management options available to managers of larger properties.

Early land ballots have also been criticised in the past as applications were open to all-comers, including unskilled and ill-prepared persons (Lilley 1973). There was no acknowledgment for experienced sheep operators for the ballot and subsequently any person who could raise the application fee could take part in the lottery draw. New leaseholders often held their land for only a mandatory period, before disposing the blocks for monetary gain. Conditions for ballots were later changed following an enquiry, where preference was granted to applicants who could prove to have suitable experience and finance to manage an acquisition.

Land resumptions and stocking rate change

The specific dates when land resumptions (Table 4.3) took effect (in terms of stocking rate) were not obvious from Lilley (1973). In order to select the year when each resumption took effect, the time-series of total stock numbers (DSEs) around the time of each resumption were examined. The year when there was a marked decrease in stock numbers was taken as the year when the resumption became effective (e.g. 1893, 1897, 1935). Where there was no marked change in stock numbers, the year of resumption (as reported by Lilley 1973) was taken as the year for property area change and stocking rate calculated accordingly (e.g. 1914, 1949). It was assumed that the property managers responded appropriately to the loss of grazing land by reducing their stock numbers.

4.2.5 Specific periods: case studies in managing variability

There are well-documented periods in Queensland's grazing history where widespread climatic extremes, e.g. drought or flood, have caused severe hardship for pastoral enterprises. These extreme events sometimes accompanied or created drastic market fluctuations that have seen landholders walk off properties. The focus of this section will be on widespread extreme incidents that have impacted on both the study properties, although localised climatic extremes have occurred in the past and have been documented. It will include livestock and vegetation effects, as well as management responses initiated to reduce the impact on the resource and secondary production. For Lansdowne, Lilley (1973) documented events up to the end of the 1960s providing 'case studies' in the management of climate and economic variability.

Turn-of-the-century drought

The year 1884 saw Lansdowne with the highest stocking rate (Figure 4.2a) in its history (1.36 DSE/ha). Relatively low rainfall in late 1884 was followed by flood rains in early 1885. While numbers were reduced by sales and agistment (at Evesham station, Longreach), losses from January to June 1885 totalled 27,000 sheep (≈10% of total livestock) giving a stocking rate of 0.84 DSE/ha by the end of 1885–a reduction of 37%. In 1888, with annual rainfall of only 275 mm, Lansdowne's low stocking regime at the time may have accounted for the increase in stock that occurred, while neighbouring properties sustained heavier losses than in the previous major drought of 1885. The next seven years to 1893 were characterised as 'fair' seasons with the stocking rate oscillating (0.62–0.97 DSE/ha) around the long-term mean (0.86 DSE/ha).

In 1894 and 1895 Lansdowne received rainfall of 952 and 533 mm respectively, both above the median rainfall (483 mm). By 1897, stock numbers had risen again to 1.14 DSE/ha (Figure 4.2a). However, it was not until 1903 that above-median rainfall was again recorded. In this period, Australia was to face the

'Federation' drought where livestock numbers in Queensland were depleted by more than half (Daly 1994). By 1902 (Figure 4.2a), stock numbers had decreased to their lowest level recorded (0.36 DSE/ha) as had Tambo shire numbers (0.23 DSE/ha). The decline in Lansdowne numbers represented a 68% reduction in livestock from the peak of 1897, six years previously, while wool production also declined ≈70% from ≈2,200 bales (1897) to less than 700 bales (1903). Similar decreases are apparent in most Queensland and Australian agricultural commodities data (*Statistics of Queensland* various issues).

In April 1902, the Land Court sitting at Tambo and presided over by a Mr Sword, concluded that carrying capacities for the region had been greatly overestimated by graziers. Further, it was recommended that if ruinous losses were to be avoided in the future, then stocking rates should not exceed one sheep per 4 acres (1.62 ha or 0.62 DSE/ha) or the equivalent in cattle even on first-class country. The stocking rate for downs country in the Barcoo district had been previously (1884) set at one sheep to 5 acres (0.5 DSE/ha) by the first dividing commissioner (J.W. Edmonds) who had assessed rents in the Barcoo district. Sword noted that adherence to Edmonds' estimation of carrying capacity would have prevented the deterioration of the pasture and waters to the point where there was no ability to move sheep from place to place, thus leading to the death of many thousands of sheep.

Another important event for the sheep industry in this period was the first report of flystrike in Queensland in 1883 (Lilley 1973, p. 90), shortly after the blowflies *Lucilia cuprina* and *Lucilia sericata* were imported into Australia (Moule 1962). Moule (1962) stated that the rapid spread of the blowfly was due to wrinkly-skinned Vermont Merinos that had been introduced in the 1880s.

Drought and market failure – 1920 to late 1940s

Stocking rates in the mid 1920s reached 1 DSE/ha (Figure 4.2a), no doubt influenced by the high wool prices at this time (e.g. 1924). Fires which occurred in the summer of 1925–1926 signalled the start of 'troubled times', with rainfall for the first six months of 1926 totalling only 102 mm, almost half of this occurring as a single fall (42 mm). As a result, large-scale supplementary feeding was introduced for the first time on Lansdowne; agistment was not an option given the drought was widespread across much of Queensland's sheep areas. Grain was accessible at the time and when no pasture roughage was available, lucerne was provided. Since the industry was relatively prosperous at the time many large stations followed suit. However, numbers in 1926 dropped 33% to 0.67 DSE/ha, with rainfall for the year amounting to a low of 252 mm. Lilley (1973) commented that the logic of hand feeding was later questioned, for there was no real consideration as to how long the drought period was to extend and no knowledge of the reliability of fodder supplies. In future drought periods, this bad feeding experience, coupled with low wool and sheep prices, led most property managers to believe that it was better to let the sheep survive as best they could, rather than provide supplementary feed.

Following the 'boom' wool prices of early 1925 there was the classic 'bust' (1926 collapse followed by the Wall Street stock market fall in 1929 giving rise to the Great Depression). Wool prices per bale on Lansdowne fell 73% from a peak of £41 (1924) to £11 (1930). It was not until after the wool price collapse that the ramifications of the extensive feeding program in 1926–1927 were realised, where the cost of keeping a sheep alive over the drought period had been £2, while their market value was to fall to a mere five shillings (Lilley 1973). Payne and McLean (1939, p. 17) noted in their report to the Queensland Government that:

> In saving their sheep in this manner the graziers did an immense service to the State, and prevented the effects of drought being brought into every business and into every home. They averted an economic crisis for the State, but at the cost of impoverishing themselves.

In the early 1930s, Lansdowne stocking rate fluctuated well below the long-term mean of 0.86 DSE/ha (Figure 4.2a), possibly influenced by both the poor market for wool, and the variable seasons. It is interesting to note that while the property would not be considered heavily stocked, two years of poor rainfall (1934–1935) saw numbers drop 33% to the second lowest point in the property's history (0.47 DSE/ha). Sheep were fed in late 1934 to mid 1935, when relief in the form of winter rain saw the practice discontinued. Within two years numbers had returned to the pre-drought stocking rate of 0.8 DSE/ha.

It is not possible to comment on the impact of stock retention throughout the drought of the late 1920s and early 1930s especially for Lansdowne. However, C.T. White (1935, p. 268) in a report to the Minister for Agriculture and Stock wrote:

> During the year 1933 considerable attention was given to statements from various sources that the Mitchell grasses of western Queensland were diminishing, due to prolonged droughts and continued stocking.

When the drought broke in 1933 an investigation of recovery was conducted (Everist 1935). The investigation found that continuous overstocking and the incidence of droughts had destroyed the 'root-stocks' of Mitchell grass in some situations and hence recovery in 1934 was not apparent. Nevertheless, it was thought that reduced grazing pressure and the return of favourable seasons would allow recovery to occur from seed.

The year 1942 saw war-inflated wool prices and the highest number of sheep in Queensland's history (26 million head, Gramshaw and Lloyd 1993). The mean of six years property rainfall (1943–1948) was 379 mm, 25% below the long-term mean of 515 mm. In this period the end of the Second World War coincided with the widespread drought of 1944–1945. In some of these years the ewes were not joined, hence the yearly stepwise decline in stocking rate, which 'bottomed out' in 1948 at 0.58 DSE/ha. Only stud ewes were fed in 1946, lucerne being the main supplementary feed as grain was in short supply.

From 1931 to 1950, Lilley (1973) stated that 0.73 sheep/ha was a safe carrying capacity for Lansdowne as this was the average for that period. Although this number is below the long-term mean (0.86 DSE/ha), numbers were maintained during this period by supplementary feeding practices. Thus the estimation of 'safe carrying capacity' has been confounded with the management practice of supplementation, because it allowed animals to remain on the property when pasture resources were low. When feeding animals was not an option (e.g. cost-prohibitive), removal from the property via sale or agistment was generally practised or, in rare cases, the animals were left to fend for themselves and many died.

Wet and dry years, bushfires, floods and wool boom – the 1950s

The 1950s included sequences of wet years that had obvious positive impacts in terms of pasture production, but also included problems indirectly associated with high rainfall events. Wool demand lifted to more than double as a result of the Korean War, to reach a top of £173/bale for Lansdowne wool – the highest price ever. Despite the highly inflated market, and the potential for increasing livestock numbers, the stocking rate did not climb appreciably until the end of the decade (Figure 4.2a). Lilley (1973) reported that property stability was the main objective, with shearing numbers maintained between 50,000 and 60,000, and post-shearing sales reducing the flock to ≈40,000 sheep.

High rainfall in 1949 brought on a fly-wave, and again in 1950 with 40% of Lansdowne weaner sheep affected (Lilley 1973). Despite the effectiveness of chlorinated hydrocarbons such as BHC spray, the constant wet conditions prevented mustering and effective treatments. Losses of 5% in grown sheep and 12% in weaners were recorded on Lansdowne while mortalities of up to 25% were reported in other localities. The reduced losses were attributed largely to the controversial practice of 'mulesing' pioneered by J.H.W. Mules in the late 1930s.

The other consequence of the high rainfall period was high grass biomass – and bushfires! In 1950 Lansdowne sheep and improvements were fortuitously insured for the first time against fire with the total sum insured being £273,000. Fire became a dominant feature of the 1950s. An area of 4,000 ha was burnt out before the winter in 1951 with minor losses, while other properties incurred losses of up to 3,000 head. The next major fire occurred early the following year, where some 45% of the property (28,000 ha) was reduced to ash. Again sheep losses were small considering what could have been the outcome, although much fencing was damaged (but was covered by insurance). In 1953, despite being the last of three dry years, there were more fires in the district. As a result of the loss of pasture, a large-scale feeding program costing £15,000 was initiated on Lansdowne.

The year 1956 had the highest annual rainfall since 1890 (1,216 mm). In February 1956, 230 mm fell in just five hours resulting in all creeks in flood, causing some sheep losses and a great deal of damage to fencing. Other problems included fleece rot and flystrike from excessive rain and the longest shearing strike on record (1955, 10 months).

High spatial variability of rainfall within the district is well illustrated by 1958 when Upper Lansdowne received adequate rainfall, while Lower Lansdowne was not so fortunate. As a result breeding ewes (8,000 head) were fed from September to December before storms alleviated the emergency.

Drought years – the 1960s

Lilley (1973) classified the early 1960s as a 'run of good seasons' and stated that the more 'naïve' graziers envisaged that some normality would ensue, as 1959 through to 1964 had a mean annual rainfall of 586 mm. Stock numbers peaked in 1960 at ≈1 DSE/ha (Figure 4.2a) and then oscillated around the mean stocking rate (0.86 DSE/ha) until 1983. A ceiling number of cattle was set for the property at 1,000 breeders as a trial, owing to expenses involved in changing infrastructure to suit the more destructive behaviour of cattle (e.g. to waters and fencing). Cattle until this time had been a minor component of the company's interests.

The 'run of good seasons' ended in 1965 with the start of another drought causing widespread livestock losses in Queensland and northern New South Wales over the period 1964–1966 (Miller *et. al.* 1973). The total rainfall for 1965 was the third lowest recorded (197 mm), of which 130 mm was received in December of that year. Feeding commenced in April 1965 and continued until mid December, with a total of 44,000 sheep and 1,000 cattle fed. Agistment was not available due to the widespread nature of the drought. Lilley (1973) reported that the cost of drought feeding amounted to an incredible $138,344. The subsequent high lamb-markings for 1965 justified the decision to feed and more than covered the loss of a large number of ewes that had lambed on the feed and suffered pregnancy toxaemia (as explained further in the next section).

Low rainfall in 1966 resulted in agistment of the maiden ewes to Blackall and feeding of stud ewes at the close of the year. Rainfall was low again in 1967 (294 mm), and breeders were fed once more before the season broke at the end of the year. Despite the poor seasonal conditions, the stocking rate increased 32% over these two years to approach 1 DSE/ha in 1967. An amendment to company policy was also made in 1967, from an earlier decision (1960) to increase the cattle herd to a maximum of 4,000 breeders, although as stated earlier, the maximum number of breeders ever reported was ≈2,000 (1982).

Temporary relief occurred in 1968 with well distributed, slightly above median rainfall. The resultant pasture growth ensured satisfactory livestock production. The following year 1969 was poor in terms of rainfall (346 mm), whereupon a 20 ha farm at Gatton (south-east Queensland) was purchased for the sole purpose of providing lucerne to Lansdowne in the event of drought. The farm, however, was sold in the 1970s.

4.2.6 Impact of climate variability on births and deaths

The positive balance between reproduction and mortality (i.e. 'births' and 'deaths') is fundamental to the survival of self-replacing flocks and herds. Extremes of climate variability have direct (high temperatures and floods) and indirect (through pasture growth) effects on these processes. The detailed records of Lansdowne provide an opportunity to document the potential magnitude of these effects. Most favourable lamb marking years recorded in Lansdowne's history were correlated with a specific interaction of climatic parameters (e.g. rainfall, temperature, relative humidity) which produce seasonal conditions that graziers consider optimal for production of high quality pasture necessary for conception and subsequent nutrition of mother and offspring (lamb, calf). The chance of such a season, or a 'run of good seasons', occurring in western Queensland is far out-weighed by low rainfall events or deluges that often have a more devastating effect. There are numerous occasions in Lansdowne's history where the adverse effects of the variable climate have resulted in high mortality rates and impacted on matings and subsequent births–a number of these instances have been detailed in Section 4.2.5. While it may be considered that rainfall *per se* is the lifeblood of herds and flocks, the following accounts are intended to illustrate that good or bad fortune has, in part, depended upon the timing, intensity and duration of a rainfall event within a season. This is often in spite of management intervention (e.g. stock reduction or supplementation).

Lamb marking percentages on Lansdowne have varied over time. There have also been years where ewes and rams were not joined for fear of losing both the breeder and the offspring. When animals were mated, markings have ranged from <30–90%. In 1982, new lamb losses due to heat exposure (only 33% marked) and heavy drought losses of unsupplemented ewes (17%) highlight that modern husbandry and infrastructure have not reduced the risk of severe climate impacts on production.

Pregnancy toxaemia is one of the conditions that may affect ewes prior to lambing, especially those carrying twins (Caple *et al.* 1990). Undernutrition is the predisposing factor, although well-conditioned animals are also affected at this stage of pregnancy if they are subjected to sudden food deprivation or stress. Situations when this may occur include untimely rainfall resulting in boggy conditions, making travelling difficult and reducing pasture on offer when animals are yarded to be moved if pasture resources are denuded. There are reports of this condition having a major effect on flock numbers on Lansdowne in specific years (e.g. 1946, 1965 and 1993).

In some years (e.g. 1943), it was recognised that the prevailing seasonal conditions on Lansdowne were not likely to produce sufficient feed for lambing or that, due to the lack of feed, it was a better option not to join the rams and ewes. This was a risk-averse decision where, if seasonal conditions continued to deteriorate, potentially a year's lamb crop would be lost. Dry sheep are also easier to manage and maintain in harsh circumstances. A good lambing in a preferred season would, to some extent, make up for a poor season as was shown in a number of years when the stocking rate increased substantially in only a few years (Fig 4.2a).

In central and south-western Queensland it is possible that a lack of pasture due to a poor summer season may be 'saved' by the advent of winter rain. Winter rainfall in the west often produces a highly nutritious herbage crop or 'forbs' (Orr and Holmes 1984). Lansdowne livestock often benefited from winter rainfall events (e.g. 1977, 1983, 1990).

Episodes of sustained high summer rainfall and pasture growth, but in which livestock performed poorly despite the favourable conditions, have occurred on Lansdowne (e.g. 1886, 1950, 1982, 1991 and 1995). These events were described as 'grass gone rank' or 'protein droughts', where available nitrogen in the system had been used up and was thus very dilute in the plant resulting in poor animal performance.

High rainfall events were also often associated with flooding. Lansdowne sustained their greatest losses in February 1885 when floods resulted in the deaths of 27,000 sheep. This event was preceded by three years of below median rainfall (1883–1885). The effects of drought followed by flood are shown by the large decline in stocking rate in Figure 4.2a.

Another problem associated with periods of high rainfall and pasture growth was uncontrolled wildfires (e.g. 1887, 1891, 1906, 1925–1926, 1951–1953, 1994). From this record it is noted that the frequency of wildfires has diminished over time. Mitigation techniques such as fire-fighting units (water pumps and water trucks), firebreaks and controlled burning may have been in part the reason for the decline in widespread wildfire events (Lilley 1973).

Unless substantial rainfall followed the fire incidents to rejuvenate pasture, hardship ensued as the intensity of such fire events generally burnt all available forage in the locality. Even when livestock mortalities directly due to fire were not high, the combined loss of pasture and lack of further rain induced a drought situation, as shown by the associated reduction in stocking rate (Figure 4.2a).

Prolonged rainfall events on a full-woolled sheep can wet the fleece allowing the fleece-rot organism (*Pseudomonas aeruginosa*) to proliferate, which in turn predisposes to flystrike. While management tools such as mulesing, crutching, tail docking, jetting and strategic shearing guard against flystrike incidence, the weather that initiates fleece-rot often prevents graziers from handling and treating their sheep. In 1950, 40% of Lansdowne weaners were affected, with 5% and 12% losses of adults and weaners respectively. Lansdowne also suffered major flystrike problems in 1883, 1896–1897, 1902, 1909, 1924, 1949–1950, 1955–1956 and 1993. In some fly waves, flystrike has resulted in the death of three million sheep nationally and cost the Australian sheep industry $150–160 million annually (McLeod 1995, Lehane 1999).

In 1924, Lansdowne's managers changed their shearing policy in order to reduce the risk of flystrike. At the time it was customary not to shear weaner sheep, but to wait until their second year, as wool from these animals was readily saleable into a niche market while the light fleeces from lambs were not nearly as saleable. However, by 20 months of age the hoggets often suffered losses due to flystrike and grass seed (e.g. white speargrass). As it was considered only a matter of time before the premium for such wool was eroded, it was decided to shear the sheep as weaners thus avoiding further sheep losses.

Another management strategy to reduce the risk of flystrike was the introduction of mulesing in 1945. This was done by 'mulesing' the maiden ewes each year until the entire flock was treated. The practice comprised the removal of the skin at the rear of the sheep with the formation of scar tissue preventing fly strike. An immediate reduction in the incidence of flystrike in the treated animals was observed.

4.2.7 Summary of stocking rate strategy

There is evidence to suggest, not only from Lilley (1973) but overall property condition and productivity at present, that Lansdowne livestock numbers have been carefully moderated by management throughout the entire period of pastoral use. However, it is not known from our present sources (unless specifically disclosed) to what extent mortalities, sales, agistment or reduction in reproductive capacity (e.g. low lambing rates) contributed to large declines in stocking rates during extreme climatic events such as drought.

Nevertheless it is significant that throughout Lilley's monograph, there is an acknowledgment that the resources are not to be taken for granted and if they are pushed too far, elements do collapse. The first of these occurred in 1883–1884 when there was recognition that the stocking rate (1.34–1.36 DSE/ha, Figure 4.2a) was too high for the country regardless of the time, type of season or state of improvement. The highest stocking rates used subsequently have been ≈1.2 DSE/ha.

An analysis of time-series of stocking rate is presented at the end of the chapter.

4.3 Moble Station

4.3.1 Property background

The original selection of Mobel (sic) Creek (16,188 ha) was made by John Costello from Goulburn New South Wales in 1867–1868 (Durack 1968). During the period 1867–1877 the Costello and Durack families collectively amassed some 4.4 million hectares in south-west Queensland and the channel country. The Moble holding came into the ownership of the Rutledge family in 1923, with one other previous owner prior to the acquisition.

Property data and comments for this section were drawn primarily from the original station rainfall and stock record books (1924–1997), in contrast to Lansdowne where the publication by Lilley (1973) was the main information source. Anecdotal comments were recorded throughout the property record books relating to climatic events (e.g. droughts, floods and livestock mortalities). Livestock numbers were extracted from records that included sheep and cattle musters, shearing numbers, lamb markings, calf brandings and sales of wool and livestock. As well, discussions with members of the Rutledge family enabled a number of issues regarding management and livestock numbers to be clarified. There is also a collection of government literature/project material that contains information relevant to this section:

- Buxton *et al.* (1999) included Moble as a case study in the Droughtplan Regional report, *Is resilience to drought improved by the presence of mulga?*. This report provides a brief description of the south-west Queensland area, as well as management practices used in the region;
- observations of Moble made by Garrad and Johnston (1998) in conjunction with the project *Appraising safe carrying capacities for all properties in South West Queensland*;
- a comprehensive land system report pertaining to the *Western Arid Region Land Use Survey* (WARLUS, Dawson and Boyland 1974);
- a property map was generated by staff of the Queensland Centre for Climate Applications (QCCA) from paddock diagrams using Geographical Information System (GIS) technology and Landsat Thematic Mapper (TM) satellite imagery. The map included station improvements (e.g. fences), watercourses and land topography; and
- Hodgkinson *et al.* (1996) have involved Moble in the long-term grazing project *Tactical rest for rangeland management*. In this trial, three treatments have been imposed on grazing plots (3,000 m^2): (1) total exclusion from all grazing animals (control); (2) periodical resting from grazing animals (tactical); and (3) open to all grazing animals (continuous).

Thus there is a large amount of information available on the Moble pastoral holding that includes physical, managerial, historical and anecdotal data allowing the following analysis. We also wish to gratefully acknowledge the Rutledge family for their time, cooperation and trust in allowing valuable family records to leave their property in our charge.

Longstanding viability and property condition

The presence of a fourth generation family member on a holding the size of Moble speaks for itself in terms of the soundness of management practices and sustainability of the enterprise. While no verification of financial stability was sought from the owners, Buxton *et al.* (1999) perceived that the better managers coped with the unreliable and variable seasons typical of the region. Astute managers generally achieved higher and more consistent prices for stock and produce, as well as restricting expenditure, leading to high levels of financial performance within the operation.

Moble was used as a 'benchmark' property in the Queensland Department of Primary Industries project *Appraising safe carrying capacities for all properties in South West Queensland* (Johnston 1996, Garrad and Johnston 1998). Benchmark properties were chosen to represent land systems in good condition with a long-term domestic grazing regime. Moble was considered to be in fair to good condition with respect to the pasture and the land resource as a whole (P. Johnston pers. comm.).

4.3.2 Property features

Property area

Moble is a sheep property with a small number of cattle, located ≈60 km south-west of Quilpie (Figure 4.1; property position: latitude 26.87° South, longitude 143.93° East; Plate 4.2) with a total area of 45,200 ha (Table 4.5). Moble Creek itself runs through the property, eventually flowing into the Bulloo River when sufficient rainfall occurs.

The Rutledge brothers partnership, initially from Dirranbandi took up two 6,000 ha blocks on the Bulloo River near Toompine. The Moble holding was purchased in 1923, with an additional area (Glengarten) added to Moble in 1931. Blocks at Adavale (Wakes Lagoon station, ≈100 km north-east of Quilpie, sold 1946) and Bollon were purchased at a later date.

Land type and vegetation

Moble has a mixture of types of country ranging from the fertile Mitchell grass plains (*Astrebla* spp.) to both soft and hard types of mulga (*Acacia aneura*) on undulating ridges, channels and flats (Plate 4.2). Soils are predominantly red earths of varying depths and cover, with red and brown cracking clays also ranging in depth. Understorey shrubs and grasses include false sandalwood (*Eremophila mitchellii*) and turkey bush (*Eremophila gilesii*), wandarrie grasses (*Eriachne* spp.), wire grasses (*Aristida* spp.), bottlewashers (*Enneapogon* spp.) and lovegrasses (*Eragrostis* spp.). Winter rainfall generally promotes the growth of forbs which are a useful source of fodder for livestock and often will support animals until perennials regenerate with summer rainfall (Orr and Holmes 1984).

Other timber species and communities are interspersed among the mulga with gidyea (*Acacia cambagei*), western bloodwood (*Eucalyptus terminalis*), lancewood (*Acacia shirleyi*), boree (*Acacia tephrina*) and coolibah (*Eucalyptus microtheca*) present. The creek country presents as timbered alluvial channels which 'break out' in times of high rainfall events, sometimes changing the course of the creek and the local vegetation

Table 4.5 Moble landholding changes.

Date	Details	Total area (ha)
1867	Selection by John Costello (Goulburn)	16,188
1908	Start of 30-year lease - new lease started1/6/1931	33,217
1923	Rutledge family acquisition of Moble holding	33,217
1928	Area on stock return	33,282
1931	Lease addition (Glengarten)	44,414
1933	Area on stock return	44,516
1934	Stock route excised	43,302
1998	Without stock route	43,265
1998	With stock route	45,200

Plate 4.2 A property such as Moble has a range of timber and pasture communities. These photos are taken from the Quilpie district with the aim of showing this diversity. Photo **a** shows *Eriachne* spp. (wanderrie grass) in the foreground with *Acacia aneura* (mulga) in the distance. Photo **b** shows *Eremophila* spp. as the lower woody weed component and mulga as an overstorey; both species can range in density from low to very high.

c

d

Plate 4.2 (continued) Photo **c** illustrates other members of the Acacia genus represented in the region: *Acacia tephrina* (boree) to the left and *Acacia cambagei* (gidyea) on the right. Photo **d** shows an open plain of *Eriachne* spp. with shrubland (possibly mulga) visible in the distance. Red earths appear in all scenes as a common feature of the region. *Astrebla* spp. (Mitchell grass) pasture shown in Plate 4.1 is also found in areas of the Moble property.

Photos by Robert Hassett (Pasture and land assessment officer, Natural Resource Sciences, Queensland Department of Natural Resources, Mines and Energy).

distribution. The distribution of soils and vegetation is available on a paddock basis from the WARLUS Land Systems survey (Dawson and Boyland 1974).

Durack (1968, p. 86) quoted a number of descriptions of the original selection from early journals which are of interest to this study. They include:

> The 'good hole' on Mobel (sic) Creek lay between drooping, flood-tattered paperbarks and raggy coolibahs.... The water was opaque and uninviting but it was good water for a drought year and there was enough pasture to indicate promising possibilities. It would be 'sweet country' after rain, they said, and if, because of limited permanent water, it might not sustain a large herd, it was suitable at least for a temporary place.
>
> The Bulloo ran overflowing its tributaries and soon the grass sprang sweet and succulent on the parched plains. The settlers watched the flanks of cattle and horses swell to curves of wellbeing and contentment, realising how truly Landsborough had described this as a country of swift, almost miraculous change (p. 87).

With reference to the first quote, no paperbarks have been sighted in recent times (B. H. Rutledge pers. comm.).

The various species of Mitchell grass found on Moble are considered the 'mainstay' feed for livestock. The red soils are considered to be moderately deep and generally fertile (B. H. Rutledge pers. comm.). However, the hard setting soil surface character of these soils is a constraint to pasture germination and growth. The distribution of the grasslands can change by area, perhaps due to a climatic event such as a drought or flood (B. H. Rutledge pers. comm.).

Buffel grass (*Cenchrus ciliaris*) has been planted in the past in a number of locations, including sites where mulga was pulled. However buffel did not germinate well initially and never became prolific, even where there was little competition for growth. Nevertheless, in recent years there has been an increase in the prevalence of buffel grass although the cause is uncertain.

The combination of low available soil phosphorus (P) and low soil moisture limits the establishment of buffel grass (Silcock and Smith 1984, O'Dempsey 1999). Low P levels retard the rate of seedling growth before soil moisture is lost. In wetter summers there is a better chance of establishment, but buffel grass may not proliferate due to lack of further seedling establishment events and the effect of grazing (O'Dempsey 1999). Buffel grass appears to have proliferated on 'run-on' areas or flooded country and these locations are considered more worthwhile to concentrate seeding programs. However, observations suggest buffel grass has not been well received by grazing animals as a feed source (B. H. Rutledge pers. comm.).

Minor soil movement from washouts and surface disruption are considered a desirable action as the hard set soil surface is disrupted and promotes herbage or pasture growth depending on the time of year and location (B. H. Rutledge pers. comm.). The result, however, is variable and unpredictable depending on the season, rainfall amount and intensity. Growth at disturbed sites may also include mulga and *Eremophila* spp. Events that may cause soil disturbance and increase the chance of pasture regeneration include:

- clearing or pushing mulga;
- creek channels which fill up with timber (eucalypts and gidyea) then break out to form new paths – silt spreads out providing nutrients and moisture, disturbing the original hard state;
- hoof action (e.g. stock camps, paths and pads); and
- vehicle tracks.

Orr and Holmes (1984) outlined the advantages of having diverse types of country. They considered that Mitchell grassland properties alone had inherent drought susceptibility, but in conjunction with mulga woodlands formed a good combination with the mulga tree, providing a drought feed source.

Climate

The climate of the south-west mulga region is described as semi-arid to arid with a highly variable rainfall (Table 4.1). A summer (September–March) dominant rainfall pattern associated with high temperatures occurs, with winter rainfall and frost incidence increasing towards the south. Rainfall has been recorded on a daily basis by the Rutledge family since 1924. Table 4.1 reveals that the mean annual calendar rainfall over this period was 316 mm, median annual rainfall was 288 mm, maximum annual rainfall was 778 mm (1956) and the minimum annual rainfall was 72 mm (1937).

Using the 'SILO' climate database (Mullen and Beswick 1998), an historical climate record (from 1957) was generated for Moble. Rainfall was derived from station records and other climatic elements were interpolated from neighbouring climate stations. The highest maximum daily temperature for the period 1957–1998 was 46° C, while the lowest minimum daily temperature was −1.5° C. High potential evaporation rates and frequent droughts are also common features of the region.

Rainfall for the period September–August was then calculated over the 74–year period to aid the analysis of livestock in a single management period and will be used from this point on. The 'rain year' as shown in Figure 4.2b averaged 321 mm with a median of 308 mm (Figure 4.2b) and range from 77 mm in 1986 to 836 mm in 1974.

The monthly mean and median rainfall values for the period 1924–1998 are shown in Figure 4.4 and highlight the predominance of summer rainfall which has a direct impact on pasture growth, livestock production and management practices. Variability in monthly rainfall is shown in Table 4.6 relevant to management decisions made at monthly, seasonal and decadal timescales.

Whilst there has been no trend in annual rainfall, the proportion of winter rainfall has been increasing particularly since the 1960s (Figure 4.5). Lawrence *et al.* (1991) also found a similar trend in winter rainfall in the Maranoa mulga woodlands where 24% of annual rainfall fell in winter in the period 1946–1972, and 38% in the period 1978–1989. These analyses support observations of the current owner (B. H. Rutledge pers. comm.) and ecologists (A.J. Pressland pers. comm.).

As discussed later, changing distribution of seasonal rainfall (increasing winter rainfall and decreasing summer) affects the pasture resource base and livestock nutrition.

Fire

It is generally believed that the grass-dominated open spaces of the mulga lands noted by early settlers were due, in part, from the regular occurrence of fire (e.g. Mills 1989). There are also other hypotheses that will be discussed in the following section.

Fire is not currently considered as a management tool on Moble (B. H. Rutledge pers. comm.). Acacias (including mulga) are highly susceptible to fire and therefore it is not regarded as an option, even to manage woody weeds or to control thicker stands of mulga where the lack of grass biomass also limits the chance of this event occurring in any case. Mulch (i.e. organic matter) from pushing mulga is thought to enhance pasture regeneration far more than potash resulting from fire (B. H. Rutledge pers. comm.). Pasture is regarded as an extremely limited resource due to the low and variable rainfall in this region and to burn the pasture resource is seen as wastage (B. H. Rutledge pers. comm.).

The last notable fire events (wildfires) on Moble were in the 1950s and the 1970s where approximately 5 and <1% of Moble were burnt respectively. The 1950 fires were so intense that mulga on the ridges was burnt 'to the stump'.

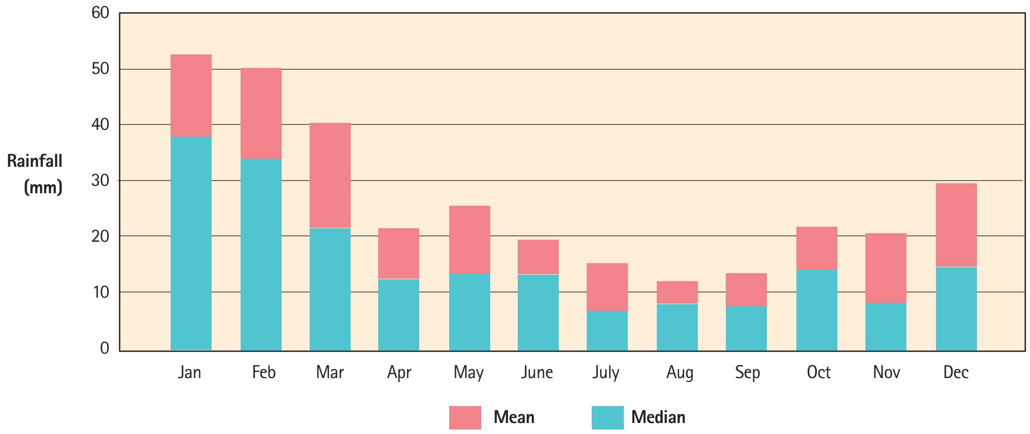

Figure 4.4 Mean and median monthly rainfall of Moble for the period 1924–1998 (May 1998 was the last month of rainfall data included in the analysis)

Table 4.6 Coefficient of variation for Moble monthly rainfall for 1924–1998.

Month	Coefficient of Variation (%)	Month	Coefficient of Variation (%)
January	129	July	136
February	122	August	116
March	141	September	129
April	153	October	123
May	149	November	120
June	111	December	161

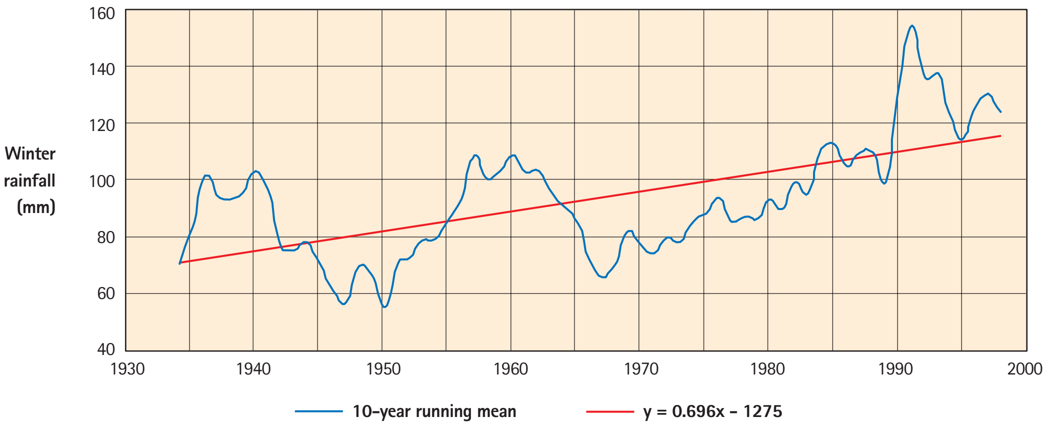

Figure 4.5 Moble winter rainfall (April–August) 10-year running mean showing increase since the 1960s.

Mulga shrubland thickening

The mulga shrubland on Moble has increased in area and density over time (B. H. Rutledge pers. comm.). In the 1930s and 1940s the country was described as being sparsely timbered with the present timber/woody species. A consensus among graziers, photographic evidence (Mills 1989) and historical anecdotes (B. H. Rutledge pers. comm.) suggest that woody shrub densities throughout south-west Queensland have increased in at least the last 30 years as reported also for eucalypt woodlands (Burrows *et al.* 2002). While there is some concern that mulga is now too thick in a few isolated locations on Moble, it is not seen as a major problem due to its capacity to be used as a fodder resource. Similarly, there are observations of *Eremophila* spp. thickening in areas of Moble, but it is not thought to be a great concern (B. H. Rutledge pers. comm.).

Rainfall variability is believed by the property managers to be the reason for the change of state from open mulga to closed thickets on Moble, not lack of fire (B. H. Rutledge pers. comm.). While average annual rainfall has remained constant at 250–300 mm (Table 4.1), the distribution, as stated previously, has moved towards the winter period from the 1960s onwards (Figure 4.5) contributing to the growth of mulga and woody weeds along with decreased grass regeneration and growth. After pushing mulga, distribution and timing of rainfall events are regarded as being the most important determinants of whether mulga, woody weeds or pasture regeneration occurs (B. H. Rutledge pers. comm.). Burrows (1974) advocated that mulga regeneration after pushing may be controlled by heavy stocking of sheep during dry winters. However, this was not the observation on Moble where sheep were seen to have an aversion to young seedlings (B. H. Rutledge pers. comm.).

Other hypotheses of how and why mulga and thickening woody weeds (e.g. *Eremophila* spp.) have occurred include overstocking, reduced competition from grasses, lack of fires and reduction in rabbit numbers (Burrows 1971, Mills 1989, Lawrence *et al.* 1991). Mulga is a surface-rooted species (Beale 1994) and trees in the adult stage limit the growth of surrounding shrubs and will generally out-compete perennial grasses (Harrington *et al.* 1984). Grass and trees may establish together, but a 'hierarchy of influence' exists where a tree's size and ability to outlive other species result in its survival. However, adult grasses can out-compete trees and shrubs for moisture at the seedling stage which may prevent the woody plants from establishing. Thus, any event that reduces the amount of pasture (e.g. overstocking) increases the potential for seedling establishment. As stated earlier, fire is thought to play a major role in tree/shrub dynamics by killing off young seedlings. However, suitable high rainfall to produce fuel loads adequate to carry a fire may occur only between two and five years in 100 years in the mulga region (Harrington *et al.* 1984). Furthermore, such high rainfall seasons can lead to mass germination of woody species (W.H. Burrows pers. comm.).

Perhaps the reason for the existence of a number of hypotheses is that several climatic (e.g. rainfall, relative humidity), management (grazing pressure) and physical (fire, soil moisture, competition) factors have coincided at critical times to initiate this phenomenon. Mills (1989) and Lawrence *et al.* (1991) stated that a combination of overstocking, decline in rabbit numbers, and lack of summer rainfall has contributed to the woody weed problem. Rabbits have been regarded as a control of woody weeds through their ringbarking behaviour (Lawrence *et al.* 1991), and especially in districts south of Cunnamulla and in New South Wales (W.H. Burrows pers. comm.). However, it is argued that rabbits contribute to the total grazing pressure exerted on pasture and it is only when the pasture resource is completely denuded that rabbits divert their total attention to shrub matter (Rolls 1984). At Moble, rabbits were thought not to have had an impact on woody weeds or mulga (B. H. Rutledge pers. comm.).

Booth (unpublished) and Mills (1986) suggested that shrub establishment in mulga lands occurs as a series of episodic events. Mills (1986) and Silcock (1999) believe that the sequence of a wet winter followed by adequate summer rainfall is an optimal combination for woody weed seedling establishment. While such a

scenario could also be considered as beneficial for summer perennial pasture growth, in the circumstances of a heavily grazed system, there would be little competition from pasture growth and also reduced chances of a fire event. Winter rainfall alone favours woody weed growth patterns while perennial grass growth is restricted to summer rainfall only (W.H. Burrows pers. comm.).

Periods when shrub establishment was likely to have commenced were prior to the mid 1950s when observations of shrub thickenings were first made (Mills 1989). Monitored transects in south-west Queensland during 1964–1984 confirmed that substantial increases in woody weed density were occurring, particularly following wet winters, over the final eight years (1977-84, Burrows *et al.* 1985). It is also believed that the main episodic event where initiation and establishment of woody weeds occurred was in the above average seasons of 1954–1956, in some cases after wildfires reduced competition from perennial grasses (P.W. Johnston pers. comm.).

Feeding mulga

Mulga is considered a much-valued resilient resource for the property's operation, existing at sufficiently high densities to be continuously utilised as part of short- and long-term management strategies. The pushing or felling of mulga trees has been used as a drought-feeding tactic for over a hundred years. It has a high regrowth rate and returns to a usable state in approximately six years.

Sheep on Moble have been observed to eat mulga even in good seasons when good quality pasture is abundant (B. H. Rutledge pers. comm.). When grass is scarce and forbs are more prevalent, mulga is consumed by sheep at higher rates to supply dietary roughage (B. H. Rutledge pers. comm.). Although digestibility is low (35–55%), it is considered that sheep can exist on little else but mulga topfeed and still maintain their productivity (e.g. 60% lambing rate), if their condition has not deteriorated at the time feeding is commenced.

It is considered that one pushed mulga tree will feed one adult sheep for one week (B. H. Rutledge pers. comm.). Younger mulga trees usually have a smaller trunk with a larger canopy, but the acceptance of the feed by sheep is reduced. Thinner mulga leaf is regarded as more nutritious for sheep. When little else is growing and mulga itself is stressed, small amounts of rain (e.g. ≈8 mm) will reduce the moisture stress, freshening it up and thus producing better topfeed.

The mulga use and regeneration cycle is as follows:

- young mulga is unpalatable to stock (due to high tannin content) and hence it is able to continue to grow to maturity, or is selected when needed once more for topfeed (B. H. Rutledge pers. comm.);
- the mature mulga tree is pushed over for fodder;
- the pushed tree dies (≈85% of cases), the time to return to re-harvest state in good seasons is approximately six years (10–12 years in poor seasons);
- the pushed canopy provides feed for sheep and cattle;
- where the tree is uprooted, a seedbed is provided for pasture grasses to establish and/or mulga seeds to germinate;
- the canopy provides shade and creates a moist, humid zone for seed germination and fallen branches also protect young seedlings from being grazed.

Before heavy machinery became widely available, mulga feeding was measured at the rate that it could be felled. One man using an axe could feed 1,200 sheep per week by felling 1,200 mulga trees. It was once considered that one limb of the tree should be left from which to regenerate; this is now known to be unnecessary (B. H. Rutledge pers. comm.). Much information is now available (e.g. Everist 1986) with respect to feeding mulga, its effect on animal nutrition, additional supplementation necessary to maximise the benefit of scrub feeding and steps to follow in order to decrease detrimental effects on the resource.

Oxley (1987a) undertook an historical analysis of Thurulgoona station (Cunnamulla). Livestock on this property were depastured predominantly on Mitchell grass plains and Warrego River overflows (W.H. Burrows pers. comm.). In the analysis, Oxley (1987a) described the 'mulga shortages' that resulted from large-scale mulga feeding carried out in previous droughts. In the 1902 drought, there were extensive areas of mulga cut (90,000 sheep fed), with edible shrubland reduced in 1907 to a variety of non-mulga species (e.g. *Atalaya hemiglauca, Ventilago viminalis, Grevillea striata*). Through a quick succession of pasture shortages where mulga was again utilised (1907, 1910–1911, 1915 and 1929), it was stated that edible scrub was being denuded. By 1929, the scrub that remained on the property was of poor quality, with the best mulga having already been felled. By the 1940 drought it was decided that scrub cutting was not an option due to the shortage of available edible scrub and that labour was regarded as 'exorbitant', low in quality or non-existent. Hence, it can be seen that use of mulga as a feed source needs to be managed to ensure its long-term availability.

Other herbivores and pests

Macropods are considered the main competitors to domestic livestock with respect to the pasture resource (B. H. Rutledge pers. comm.). In 1998 there were ≈10,000 on Moble with ≈3,000 culled by shooters each year. As an indication of how numbers have increased, there are diary records in an early Moble journal describing family expeditions across the property to view kangaroos after being sighted earlier, as it was considered a rarity to see many in a day (B. H. Rutledge pers. comm.). Timber treatment, pasture improvement and/or improved access to water were believed to be some of the reasons for the increase in kangaroo numbers (Lawrence *et al.* 1991). Improved availability of water (in terms of supply and distribution) on Moble was thought to be the major explanation for the high kangaroo numbers (B. H. Rutledge pers. comm.).

Heywood (1999) reported that the total grazing composition from 10 mulga properties (1995–1997) comprised the following: macropods (19%), goats (10%), sheep (47%), cattle (24%). Total grazing pressure calculated for the entire area was 0.3–0.6 DSE/ha, of which macropods and goats made up to ≈30% (L. Pahl pers. comm.). When animal distribution was assessed by means of dung collection (kg/ha) in two mulga paddocks, Heywood (1999) found the relative contribution to total grazing pressure for paddocks one and two respectively were: sheep, 36 and 10%; cattle, 21 and 15%; goats, 7 and 20%; and macropods, 36 and 57%. This indicates the variability in distribution of animals which may bias whole property assessments of total grazing pressure. The opinion of the Moble property owners is that it is possible to sustain macropods representing 10% of the grazing pressure, but supporting present numbers (2003) is not a sustainable situation resulting in degradation of rangeland (B. H. Rutledge pers. comm.).

Red kangaroos were initially dominant in this area of the mulga zone. A build-up of the grey kangaroo was first observed about 1968, where they now make up ≈30% of the total macropod number (B. H. Rutledge pers. comm.). The grey kangaroo is seen to utilise mulga as feed in droughts but they will not move from the resource locality and may perish in severe drought conditions. From shooters' observations, red kangaroos appear not to eat much mulga, and will migrate towards storm areas for fresh feed, thus ensuring survival. Similarly, Moss and Croft (1999) reported that red kangaroos are specialist grass eaters with a preference for younger, softer, more nutritious green plant matter.

An observation on Moble has been that the body size of all kangaroos is decreasing (B. H. Rutledge pers. comm.). A possible reason for this is that shooters harvest the larger and supposedly older animals as required by law and to obtain a larger skin/carcass. This practice is intended to promote regeneration of similar-sized animals. However, instead of this occurring, there is selection pressure placed upon the larger animals, hence genetically smaller bucks are left in higher numbers to breed smaller kangaroos. Another observation is that there are now often as many as six bucks in a mob of kangaroos, whereas in past times there was only one dominant buck with each group of females.

Dingoes are not a problem on Moble as it lies inside the 'dog' fence. However, as a precaution, the area is baited annually (≈July) with the poison '1080'. Dingoes were a major problem on Wakes Lagoon (Adavale, outside the dingo fence) during the period of ownership.

A moderate number of emus always appear to be present though they are not considered a threat to pasture due to their diet selection. However, they do cause problems to fences and are of nuisance value when mustering stock.

The number of feral pigs on Moble is estimated to fluctuate between 100 and 300 head. In 1998 they were considered very low but in the last 20 years they have become a concern to the property (B. H. Rutledge pers. comm.). Mob size and frequency of sightings vary depending on seasonal conditions. There is a substantial amount of evidence to suggest that pigs are responsible for lamb deaths on extensive sheep properties (Moule 1954, Smith 1964, Jordan and Le Feuvre 1989). Foxes are also thought to contribute to lamb mortality, while crows and hawks are believed to exist solely on carrion (Rolls 1984, B. H. Rutledge pers. comm.)

Feral goats on Moble number approximately 300–400 head (1:113 ha), with a range of 100–600 head. They have not been considered a problem until the last 20 years or so, when numbers have increased. Approximately 200 head are culled each year which is merely keeping pace with natural increase. Larger properties (≈120,000 ha) in the district are thought to carry ≈6,000 goats (one per 20 ha, B. H. Rutledge pers. comm.). Utilising goats as a constant source of income for the property is not currently practised. The average return from goats for slaughter was ≈$20. Dressed weight prices reported in *Queensland Country Life* 8 July 1999 were 120c/kg in 1998 and 225c/kg in 1999. While the wool yield from a sheep is worth a similar value per head (in 1999), sheep are seen as a more controlled, reusable investment.

Rabbits are present on Moble, but the numbers are low. Although rabbits have been part of the mulga environment for many years they have not been regarded as a serious pest, except in the house garden. This differs from the nearby Thargomindah and channel country regions where there are more sand dunes. It has been noted that numbers fluctuate due to the effect of myxomatosis. Because of low numbers it is doubtful that the rabbit calicivirus has had an impact locally (B. H. Rutledge pers. comm. 1999).

A wingless black grasshopper species observed on mulga trees occasionally causes excessive defoliation leading to the death of well-established mulga in localised areas. This event has been noticed only in the years 1992–1995 (December to March), and may also affect other *Acacia* spp. (gidyea and wattle), as well as whitewood (*Atalaya hemiglauca*), and leopardwood (*Flindersia maculosa*) trees.

Improvements – water and fencing

Development of Moble over time has contributed to the improved property condition (B. H. Rutledge pers. comm.). Domestic livestock numbers have remained unchanged during recent years (Figure 4.2b) but the numbers of feral and native grazers have risen sharply due to factors such as increased watering points and timber treatment. In terms of carrying capacity, it is believed that the land is now carrying higher total numbers of grazing animals than ever before without deterioration of the resource base.

Fencing on Moble was carried out as a lease requirement and has included erection and maintenance of sheep-, rabbit- and dog-proof netting fences. From early journals it was reported that boundary fences and internal paddocks were established in 1924–1925, 1928–1930, 1932, 1933–1934, 1936, 1938, 1941, 1946, 1951–1953 and 1957. The high wool prices of the 1950s provided a major impetus for improvement programs.

Two sub-artesian bores have been established on the property, but were abandoned due to the high saline water content. There are records of the construction and maintenance of weirs (Moble Creek) and catchment-fed earth tanks (dams) in 1915, 1925, 1926, 1936, 1945, 1950, 1951, 1956, 1958, 1980 and 1985. Many of the tanks were deepened after a number of years to increase water-holding capacity.

Although there is no artesian bore on Moble itself, a bore drain of 16–18 km in length does run through the property. The source of the artesian water is from a borehead on the Cooper/Bulloo watershed (Whynot station) that was originally set up by the State Government in 1929 as a trust, where the graziers would repay the capital cost over time. The bore has a total of 130 km of boredrains servicing various properties. Graziers who use the communal bore contribute to the maintenance of bore drains that service their property.

4.3.3 Stock numbers

Moble was initially depastured by cattle at the time of selection (1868), with sheep brought in as early as 1880 (Durack 1968). Patrick Durack travelled from Goulburn in 1868 with 100 head of cattle, whilst at the same time John Costello was starting with approximately twice this number from Warroo Springs, NSW. At the time of analysis (1999) Moble was stocked with 10,000–12,000 sheep and 400 cattle (i.e. 13,000–15,000 DSE).

Stock returns and stock books (cattle and sheep) from the property were compiled into one record of annual livestock numbers for the period 1923–1996 in terms of DSE/ha (Figure 4.2b, Table 4.7). Where possible livestock numbers were extracted for the same approximate time each year (August), which coincided with the lowest rainfall period of the year (see Section 4.3.2). This approach worked well for sheep although shearing varied from early in the year through to August. Horse numbers were relatively low and did not vary greatly within one year. However, as discussed later, the calculation of cattle numbers was more difficult. Factors used to convert the various classes of sheep and cattle to DSEs are shown in Table 4.8.

Sheep numbers

The 'stock returns' book was used to supply sheep numbers for the period 1923–1934. Subsequent Moble sheep numbers and management (shearing, lamb marking, sales, purchases) data were recorded in the 'sheep book' (1936–1989) and computer spreadsheets (1989–1996). However, a year's stock return (1935) between the first and second books was missing and the number was taken as that recorded for the previous year (1934).

Cattle numbers

The 'stock returns' book was similarly used to supply cattle numbers for the period 1923–1934. The 'cattle book' had information on cattle musters (paddock basis), along with sales and purchases for the period 1938–1978. For the period 1935–1937 it was assumed that cattle numbers remained constant from 1934 as again no records were available. For the period 1979–1996 it was assumed that 400 adult cattle were present (B. H. Rutledge pers. comm.), representing ≈30% of total DSE.

Annual cattle numbers were obtained from the stock books to coincide with sheep numbers and rainfall. The difficulties in cattle accounting were as follows:

Table 4.7 Descriptive statistics of livestock numbers for Moble and Quilpie shire.

Statistic	Moble		Quilpie shire
	(1923–1996) [a]	(1952–1994) [b]	(1952–1994)
Mean (DSE/ha)	0.29	0.31	0.15
Standard deviation (DSE/ha)	0.06	0.05	0.03
Coefficient of variation (%)	21.2	17.4	16.9
Maximum (DSE/ha)	0.48	0.48	0.21
Minimum (DSE/ha)	0.17	0.21	0.10

[a] Includes total record period for Moble
[b] Includes same record period for Quilpie shire statistics

Table 4.8 Factors used to convert Moble livestock to Dry Sheep Equivalents for analysis.

Stock class	Conversion
Lambs	0.5
Weaner sheep	0.6
Adult sheep	1.0
Calves	2.1
Weaners	3.5
Heifers	5.6
Cows	7.0
Steers	7.0
Bullocks	9.1
Bulls	10.5
Adult horses	7.0

- in the semi-arid Quilpie climate, there are no cattle ticks and reduced incidence of parasitic worms. Once male calves were weaned there was little need to disturb them until it was decided they should be sold, thus most musters and recordings involved mainly breeders and calves;
- when steers and bullocks were mustered prior to sale, these data were used to adjust previous cattle numbers for the year in which these animals were not reported;
- it was difficult at times to track animals moved from one paddock to another and hence there was the potential for animals to be double counted; and
- livestock terminology is subjective. While it was assumed that steers and bullocks were rated 1.0 and 1.3 AE (equivalent to 7.0 and 9.1 DSE), respectively, it was not certain what actual age or liveweight they may have been.

There are possible errors in the estimation of total numbers for all livestock for all years owing to difficulties in obtaining clean musters over the large well-shaded (timbered) paddocks, rough hills and deep channels. Sometimes up to 100 sheep per paddock could be left unmustered. During the Great Depression (starting 1929) and the following war years the labour resource was also unreliable and added to the problem (B. H. Rutledge pers. comm.). Livestock were also transferred to and from another property owned by the family, 'Wakes Lagoon', until it was sold in 1946. Although many records exist of transfers, sales and purchases, it was not certain that all transactions were recorded in the stock books.

Table 4.7 details the long-term stocking rate statistics of both the property and Quilpie shire. Although higher than the shire average stocking rates, Moble's stocking rates were conservative (average 0.29 ranging from 0.17–0.48 DSE/ha) when compared to the long-term average values, presented by Buxton *et al.* (1999) given for properties in the same region (0.24–0.79 DSE/ha).

Sheep management

The Moble flock has remained relatively constant for a number of years (at the time of analysis, 1999), ranging from 10,000–12,000 head (total). Merino sheep are bred exclusively, with weaner wethers sold most years along with cast for age ewes (CFA, age–class when animals are removed from flock).

Controlled matings are an accepted part of sheep management in the Quilpie region, with ewes joined in autumn (March–April) to lamb in Spring (August–November). Double lambings (i.e. two lambings per year) were attempted in the past but high temperatures and unreliable seasonal conditions resulted in very poor conception and low lambing rates.

Rams are used at 1.5–2.0% of ewes joined and have been reduced to 1% in good years. In the past, up to 5% have been used without any improvement in lamb marking results. The rams are left with the ewes for ≈8 weeks, less in a good season. The current practice is to use station-bred with rams purchased occasionally from studs.

Once the last lambs are dropped, lamb marking begins (≈3 weeks old) provided the season allows. If no rain occurs lamb marking is postponed until fresh feed is available and thus lamb and ewe losses are reduced. Shearing is a once a year event and occurs approximately in May. Weaning occurs at shearing when lambs are ≈6–7 months old and rams are removed from the ewes. Sales of CFA ewes, excess young ewes (≈30%) and excess wether weaners (last year's lambs, 2 tooth) usually take place while animals are in hand (e.g. after shearing).

Mulesing was initiated on Moble when the concept was first pioneered (1930–1940s) and continues to be used as routine management. This operation reduces the incidence of flystrike and therefore mortality. Sheep are not routinely crutched as a management practice (B. H. Rutledge pers. comm.) thereby reducing handling costs ($1.00–1.50/head to yard, plus crutching cost).

Cattle management

Moble presently maintains cattle numbers at ≈250 head of poll Shorthorn breeders (400 head total), with the objective of turning off weaners (12 months old) for the feed-on market (B. H. Rutledge pers. comm.), while culled breeders are sold for the slaughter market (if the season allows). Cattle numbers have contributed an average 23% (2,760 DSE) of Moble's long-term average livestock numbers (12,145 DSE).

Bulls are left in the herd with breeders all year round, as it is not considered as critical to control matings, nor would there be as high a calving percentage (B. H. Rutledge pers. comm.). One constraint to removing the bulls during the dry season is finding feed in a smaller paddock near the homestead. Feeding the bulls is not considered an option owing to the cost and time factors involved.

Continuous mating results in calves being born all year round, with a possible peak calving in spring (B. H. Rutledge pers. comm.). Stock records indicate that mustering generally occurs in the period February to August. Branding musters were assumed to be after a rain period and fitted in with the primary sheep management.

Horses

There are currently only twelve horses on the property, none of which are used in mustering operations. Horse numbers were recorded only in the earliest stock book that covered the period 1923–1934. Assumptions were made for subsequent years in keeping with the decline in horse numbers and the introduction of motorbikes and aircraft for mustering (B. H. Rutledge pers. comm.).

4.3.4 Landholding changes

Moble did not have to deal with changes in landholding to the same extent as Lansdowne station. There was only one major landholding addition in the study period with the addition of 11,132 ha in 1931 (Table 4.5). However, the sale of the Adavale property (Wakes Lagoon) in 1946 reduced stocking rate management options as livestock were often transferred between the two properties (mainly to Wakes Lagoon). Thereafter excess Moble animals had to be sold.

4.3.5 Specific periods: managing variability

The advantage of having concise and comprehensive property records from Moble (e.g. rainfall, stock purchases and sales) is that specific events can be examined with more detail. Most early large-volume livestock transactions on Moble were sales or transfers to the other family property (Wakes Lagoon, until 1946) and will be referred to where information was available. When occasional livestock purchases were made, they were only small mobs of cattle, replacement bulls or rams, which comprised only a fraction of the total livestock component.

Drought and market failure – 1920 to late 1940s

As indicated above, the precise accounting of every change in stock numbers (births, deaths, sales, purchases, transfers) is not possible from the stock records available. Table 4.9 provides examples from the stock record book of known or estimated changes in stock numbers due to births, deaths and sales. However, the net balance of these does not match estimated changes from year-to-year in stock numbers, highlighting the difficulty of accounting for all animals in extensive grazing properties subject to high climatic variability, high mortality risk and high turnover.

Stock numbers increased rapidly from the mid 1920s to peak in 1928, the second highest peak in the 75 years of records. This increase occurred during a major drought sequence (1926-1930). Wool prices had been in decline since early 1925 (Figure 1.4). After 1928, there was a large downturn in stocking rate that was in part due to drought-related deaths. Table 4.9 in conjunction with Figure 4.2b gives an overall view of the property picture during this period. Livestock sales reflect an attempt to cope with the climatic conditions of the time. It can be seen that despite high sales and mortalities, natural increases (lamb markings) may still result in a positive livestock change (e.g. 1928). High stock losses were recorded in the last three years of the drought from 1928 through to 1930 highlighting the severity of the drought in this period. In the breaking of the drought in 1931 high lamb marking occurred resulting in a 17% increase in livestock expressed as DSEs.

A peak of 0.32 DSE/ha in 1930 was the highest point reached for this decade with a low of 0.21 DSE/ha for the years 1933 and 1936 (Figure 4.2b). In fact stock numbers for the 10–year period to 1939 averaged 0.25 DSE/ha, 14% below the long-term mean (0.29 DSE/ha) and therefore the most conservative period in terms of the property's livestock history.

Table 4.9 Change in livestock number (sheep and cattle expressed as DSE) from previous year, lamb marking, sheep mortalities, livestock births and sales for the period 1923-1939. Percentage sheep mortalities and livestock births and sales were the stated value (DSE) taken as the percentage of total livestock for the previous year. (n/e = not entered; c=only calves recorded)

Year	Livestock change (%)	Recorded lamb marking (%)	RECORDED SHEEP MORTALITY (DSE)			Total livestock births	Recorded livestock sales, transfers and movements
			Drought	Flystrike	Total sheep mortality		
1923	take-over year	n/e	n/e	n/e	n/e	252[c]	700
1924	-3	n/e	n/e	n/e	n/e	260[c] (5%)	10,174 (cattle sales)
1925	+21	n/e	n/e	n/e	n/e	36[c] (0.6%)	n/e
1926	+40	n/e	n/e	n/e	n/e	11[c] (0.2%)	n/e
1927	+31	n/e	n/e	n/e	n/e	1,246 (13%)	4,513 (47%)
1928	+11	45	1400 (11%)	1 (<0.1%)	1,541 (12%)	1,421 (11%)	3,803 (25%)
1929	-47	43	400 (3%)	30 (0.2%)	720 (5%)	1184 (9%)	2,209 (16%)
1930	+44	51	400 (5%)	200 (3%)	920 (12%)	1,336 (18%)	n/e
1931	-9	63	n/e	20 (0.2%)	95 (0.9%)	1,829 (17%)	1,274 (12%)
1932	-11	n/e	n/e	n/e	n/e	2,255 (17%)	n/e
1933	-20	50	20 (0.2%)	60 (0.5%)	180 (2%)	2,000 (17%)	1,862 (16%)
1934	+4	53	n/e	200 (2%)	265 (3%)	1,197 (13%)	1,500 (16%)
1935	0	n/e	n/e	n/e	n/e	1,197 (13%)	n/e
1936	-2	n/e	n/e	n/e	n/e	1,459 (16%)	n/e
1937	16	n/e	n/e	n/e	n/e	2,352 (26%)	n/e
1938	-5	62	n/e	n/e	n/e	1,669 (16%)	n/e
1939	9	81	n/e	n/e	n/e	2,040 (20%)	501 (5%)

Rainfall for the decade was 273 mm, 11% below the long-term median rainfall (308 mm), with a range from 395 mm in 1936 to a low of 114 mm the year after (1937).

From 1928 to 1934 the stock books and returns recorded sheep mortalities from various causes (drought, flystrike, dingo attack, lambing, flood and old age). Total recorded sheep deaths range from 1% in 1931 to 12% in 1928 and 1930. Substantial drought losses occurred in 1928 (11%) and 1930 (5%) whilst important mortalities due to flystrike were reported in 1930 and 1934 (Table 4.9). Mulesing to prevent fly strike was adopted (relatively early) on Moble after this period. Mulesing was described in Chapter 4.2.5 .

Considerable livestock sales (Table 4.9) featured in the years 1931 (12% of previous year's total livestock), 1933 (16%) and 1934 (16%), while births for those years largely covered sales and left negligible net livestock change. The 1930s started with the lowest wool prices since the early 1900s (Figure 1.4). However, the years 1933–1937 were 'buoyant', though 1938 was again in the 'doldrums'. This decade was typical of the market and climate risk that graziers had to contend with, in times where limited information on either 'source of variability' was available. Concurrently communications and transport were also constrained.

From Figure 4.2b it was apparent that Moble livestock numbers in the early 1940s did not appear to follow the same build-up that occurred throughout Queensland at that time (Section 4.2.5). Low rainfall and high livestock sales occurred during this decade, although three large floods were recorded in 1942 – one in February and two in December. The years 1945 and 1946 were poor with annual rainfall averaging only 196 mm. Lamb marking in 1946 was low (37%, Table 4.10) with flow-on impacts on property stocking rate in subsequent years. Livestock reductions were carried out to keep pace with these 'hard' years, as annual sales for the decade averaged 21% of total livestock numbers. It was therefore likely that mortalities caused the shortfall in livestock. Unfortunately mortalities were documented only sporadically (e.g. Table 4.9). The late 1940s saw a recovery (to 0.30 DSE/ha) from the effects of the 1945 drought when Moble had its lowest numbers of livestock recorded (0.18 DSE/ha).

Wet and dry years, bushfires, floods and wool boom – the 1950s

Stock numbers recovered rapidly from the 1946 'trough', with above-median rainfall (Figure 4.2b). The big rains of 1949 (525 mm) and 1950 (720 mm) saw high pasture production followed by a bad bushfire year in 1951, as was the case with other western shires (Lilley 1973, Mills 1989). The low lamb marking of 1951 (Table 4.11) reflected the fact that high rainfall and high pasture growth did not necessarily result in higher animal production because of protein dilution. The run of wet years from 1949 finished in 1956 with the annual average for the period being 509 mm. Low rainfall at the close of the 1950s set the scene for the dry years to follow.

Livestock numbers on Moble continued their climb to reach 0.48 DSE/ha in 1957, the highest level in the record of 75 years (Figure 4.2b). However, rainfall did not match the stocking rate trend (as stated in the

Table 4.10. Change in livestock number (sheep and cattle expressed as DSE) from previous year, lamb marking, livestock births and sales for the period 1940–1949. Percentage livestock births and sales were the stated value (DSE) taken as the percentage of total livestock of the previous year.

Year	Livestock change (%)	Recorded lamb marking (%)	Total recorded births (DSE)	Recorded livestock sales, transfers and movements (DSE)
1940	+16	67	1,411 (12%)	5,684 (51%)
1941	-34	76	1,542 (12%)	1,170 (9%)
1942	+61	88	2,489 (30%)	3,562 (42%)
1943	-16	93	2,374 (17%)	1,088 (8%)
1944	+18	71	2,276 (20%)	4,577 (40%)
1945	-21	46	1,791 (13%)	1,320 (10%)
1946	-12	37	1,379 (13%)	2,098 (20%)
1947	-16	61	905 (10%)	860 (9%)
1948	+18	83	1,347 (17%)	1,421 (20%)
1949	+20	79	1,744 (19%)	1,307 (14%)

Table 4.11. Change in livestock number (sheep and cattle expressed as DSE) from previous year, lamb marking, livestock births and sales for the period 1950–1959. Percentage livestock births and sales were the stated value (DSE) taken as the percentage of total livestock of the previous year.

Year	Livestock change (%)	Recorded lamb marking (%)	Total recorded births (DSE)	Recorded livestock sales, transfers and movements (DSE)
1950	+17	74	1,735 (15%)	1,203 (11%)
1951	+17	45	2,741 (21%)	4,137 (31%)
1952	+1	77	2,738 (18%)	1,397 (9%)
1953	+3	86	1,959 (13%)	3,243 (21%)
1954	-12	89	1,946 (12%)	518 (3%)
1955	+15	96	2,503 (18%)	2,139 (15%)
1956	+5	79	2,809 (17%)	5,341 (33%)
1957	+20	57	2,355 (14%)	1,809 (11%)
1958	-27	51	3,029 (15%)	6,132 (30%)
1959	-32	79	2,423 (16%)	3,537 (23%)

previous paragraph) nor the highly inflated wool prices (due to the Korean War). The increase in stocking rate for the period 1952–1956 most likely resulted from the influence of wool prices on stocking rate decisions in conjunction with high lamb markings (1952-1956).

The large decline in stocking rate from 1957 (Table 4.11) was associated with high livestock sales (e.g. 1958 and 1959). As shown above, sales have been an integral component of Moble management policy when pasture resources were stressed (e.g. 1958). The stocking rate leading up to 1957 (0.48 DSE/ha) had been well above the long-term mean stocking rate and in combination with the 1958 drought would have added to the grazing pressure.

Drought years – the 1960s

Rainfall in the early 1960s reached the median (308 mm), but with the years 1960–1965 averaged only 257 mm, heading into a major drought year in Queensland's history (1965, 112 mm). Despite the low total rainfall recorded in these years, at least one flood per year was reported, along with some or all creeks on Moble running at irregular intervals. A new flood height record at Moble homestead was set in January 1964.

Four cyclones were responsible for high rainfall and devastation across Queensland in 1964. They were: Cyclone 'Audrey' (7–11 January); Cyclone 'Dora' (2–9 February); Cyclone 'Gertie' (15–16 April); and Cyclone 'Flora' (5–6 December).

Livestock numbers rose again to 0.35 DSE/ha in 1961. From Figure 4.2b this value appears to be the upper limit of the stocking rate fluctuations for the next two decades. From this point on, numbers start to follow a pattern of lower year-to-year variation, where the stocking rate did not deviate more than 0.08 DSE/ha from the mean (0.29 DSE/ha). It was also in 1961 that the lowest lamb marking was recorded (9%), when sheep from numerous paddocks were mixed up due to drought-feeding, and lamb marking did not take place until February 1962. This event was followed by a management decision in 1965 to not join ewes at all (Table 4.12).

Table 4.12 Change in livestock number (sheep and cattle expressed as DSE) from previous year, lamb marking, livestock births and sales for the period 1960–1969. Percentage livestock births and sales were the stated value (DSE) taken as the percentage of total livestock of the previous year. (n/e = not entered).

Year	Livestock change (%)	Recorded lamb marking (%)	Total recorded births (DSE)	Recorded livestock sales, transfers and movements (DSE)
1960	+20	92	2,254 (22%)	56 (1%)
1961	+24	9	2,632 (21%)	3,731 (30%)
1962	-28	66	536 (3%)	1,189 (8%)
1963	+4	63	1,725 (15%)	638 (6%)
1964	+24	63	1,750 (15%)	3,173 (27%)
1965	+7	not joined	1,745 (12%)	3,061 (21%)
1966	-41	74	223 (1%)	2,395 (16%)
1967	+2	n/e	1,746 (19%)	1,547 (17%)
1968	+50	n/e	2,016 (22%)	273 (3%)
1969	0	n/e	1,748 (13%)	273 (2%)

Sales still proceeded throughout the decade, having an impact on livestock numbers when the sales were substantial (e.g. 1961, 1964, 1965, 1966, 1967), with an additional influence from lamb marking (e.g. 1966; Table 4.12). In years where sales were only moderate (e.g. 1960, 1962, 1963, 1968, 1969), livestock change was dependent on whether there was a significant lamb marking or not.

Rainfall in 1966 and 1967 was reasonable (352 and 384 mm respectively), but livestock numbers had not yet recovered from the earlier extended drought period (1965-1967, Figure 4.2b). The flood of March 1967 was the highest to date, as it was documented that water reached the homestead step. Previous floods were reported to have entered the house-yard and covered the garden. It was noted in this year (and other years) how 'boggy' the country became after heavy rains, making it difficult not only for the livestock to travel, but also for work to continue at crucial management periods (e.g. shearing, lamb marking, weaning, mustering for sales).

Rainfall was not 'encouraging' leading up to the 1970s (Figure 4.2b), but numbers remained above the long-term average stocking rate. Cattle numbers increased in the late 1960s and through the 1970s as sheep numbers declined because of falling wool prices (Figure 1.5 and B. H. Rutledge pers. comm.). Livestock sales decreased in 1968–1969 (3% and 2%, respectively) and Moble total livestock numbers increased by 50%.

Wet years – the 1970s

Seven years of this decade received above median rainfall (Figure 4.2b). On 14 February 1973, 142 mm was received in just 3 hours after 86 mm fell three days before (a record in terms of rainfall intensity). The ensuing flood reported in Moble Creek resulted in a 'staggering' 1,000 sheep being lost across the property. The damage to fencing was the greatest ever reported (20 km), with all earth tanks on the property damaged to some extent. The year 1974 was a rainfall 'record breaker' for most of Queensland. January rain resulted in a flood that put the house-yard and garden under water for 18 hours. The time taken for this flood to subside was also longer than any other flood to date (previous record 1964).

Accumulated pasture biomass from the high rainfall events provided the basis for subsequent bushfires on Moble. This was to be the last time fires occurred on the property to date (2003). As a consequence of the rainfall inundation and associated stock losses, livestock numbers fluctuated and sales fell in the early 1970s, despite the reasonable lamb marking figures (Table 4.13). Numbers rose then dropped – fluctuating again for the remainder of the decade with sales accounting for the stability in 1977–1978. Lamb marking was very low in 1979 (13%) probably as a result of the low rainfall, as November 1978 to April 1979 (6 months) yielded only 120 mm.

Return of drought years – the 1980s and early 1990s

The downward trend of rainfall and livestock numbers of the late 1970s continued into the 1980s (Figure 4.2b and Table 4.13). The low rainfall received in 1980 (108 mm) was accompanied by a 40% decrease in the stocking rate in 1980–1981. Remarks from property records show that 'it was a very dry year' and that 'mulga had been fed to livestock in most of the paddocks throughout most of the year'. One thousand sheep perished during this period. However, this was not reflected in lamb markings, as they remained high and stable (71–88%) throughout the 1980s.

The start of 1981 remained dry with mulga still being fed to keep stock alive. Livestock numbers 'bottomed out' at 0.21 DSE/ha in this period. However, late winter rains resulted in 'an abundance of herbage on which stock did remarkably well'. Animals selected as 'killers' for table supplies were declared as 'over fat', with lambs described as score three to four out of five (i.e. well conditioned). Cattle did well on 'good feed' in the Moble Creek channels in August but the good conditions did not last long. Rainfall of 42 mm in October was associated with a fly wave, which claimed 5% of the ewe flock (2% of total flock).

Livestock numbers improved in 1982 with a lamb marking of 80% on an annual rainfall of only 171 mm. The start of the 1983 season was worse, with September to February rainfall measuring only 33 mm and mulga was pushed for fodder from the start of September. By December, with no rain having eventuated, dams were going dry and the amount of mulga pushed was increased to feed 7,500 sheep. Despite the prevailing dry conditions a lamb marking of 88% was recorded.

Table 4.13 Change in livestock number (sheep and cattle expressed as DSE) from previous year, lamb marking, sheep mortality, livestock births and sales for the period 1970–1981. Percentage sheep mortality, livestock births and sales were the stated value (DSE) taken as the percentage of total livestock of the previous year. (n/e = not entered)

Year	Livestock change (%)	Recorded lamb marking (%)	Recorded sheep mortality (DSE)	Total recorded births (DSE)	Recorded livestock sales, transfers and movements (DSE)
1970	+5	78	n/e	2,159 (16%)	n/e
1971	+2	86	n/e	1,552 (11%)	310 (2%)
1972	-18	57	n/e	1,740 (12%)	n/e
1973	+11	82	≈1000 (8%)	1,471 (12%)	355 (3%)
1974	-19	89	n/e	1,423 (11%)	302 (2%)
1975	+44	70	n/e	2,054 (19%)	231 (2%)
1976	-13	71	n/e	1,774 (11%)	140 (1%)
1977	0	67	n/e	1,784 (13%)	1,309 (10%)
1978	+9	89	n/e	1,488 (11%)	1,081 (8%)
1979	-2	13	n/e	1,792 (12%)	n/e
1980	-20	80	≈1000 (7%)	1,194 (8%)	n/e
1981	-20	79	258 (2%)	56 (<1%)	n/e

Livestock numbers returned to be above the long-term mean stocking rate in 1984 and continued to oscillate around this figure (0.29 DSE/ha) into the early 1990s (Figure 4.2b). In terms of rainfall, 1985 was another poor year (133 mm) to be followed by an all time low in 1986 (77 mm). Despite this low rainfall livestock numbers did not approach the low point reached in 1981.

Two exceptional years (1989 and 1990) with high rainfall (538 and 443 mm respectively) saw livestock numbers rise once again. The dry year of 1991 (164 mm) may have caused an initial pasture shortage, which led to the poor lamb markings of 1991 and 1992 (33 and 36% respectively). Notes from the rainfall book for 1991 include that 'it was a dry year'; 'mulga scrub was pushed for approximately four months'; 'many waters went dry'; and 'lamb numbers were reduced'.

Annual rainfall from 1993 was close to the median or better (Figure 4.2b). The 'hard' years of the early 1990s may have influenced the stocking policy on Moble, as livestock numbers fluctuated around 0.27 DSE/ha with very little deviation. If this trend continued it would indicate that the property management tends toward a more conservative level in terms of domestic grazing pressure. However, without additional analysis, including the effects of native and feral grazing animals, it could not be stated that Moble had less overall (total) grazing pressure during the late 1990s.

4.3.6 Year-to-year variability in stock numbers compared to rainfall and other indices

The year-to-year variation of the Moble stocking rate has decreased with time, as discussed in the last section, most markedly from the mid 1980s onwards (Figure 4.2b). Apart from rainfall and pasture growth, one other factor that may have had some impact upon stocking rate was property improvements.

It was discussed previously that improvements in the form of fencing and waters were developed on Moble during the early years and have continued to be implemented over a lengthy period of time. While such improvements do not create any more pasture, they do allow a better utilisation of the pasture resource. Dalton (1989) stated that sheep in drought would graze up to 3 km from a reliable water source which equates to a 2,800 ha area, if the water source is centrally located (e.g. not in a paddock corner). Factors that influence this figure are ambient temperature and salt content of pasture (e.g. saltbush) or water (bore salinity). If sheep are exposed to high temperatures or if high saline material is included in dietary intake, they will be inclined to return to that water source more often which invariably limits the area that they graze.

Improved understanding of grazing behaviour of the vegetation system and the effect of management strategies over time, including enhanced use of improvements such as water may explain in part the reduced fluctuation in stocking rate that occurred on Moble over the past 20 years.

4.3.7 Impact of climate variability on births and deaths

Reproduction

Lamb marking statistics for Moble (1928–1995) and Quilpie shire (1952–1994) are shown in Table 4.14. Seven years of Moble lamb marking values within this period were not available and, in one year (1965), ewes and rams were not joined. For the sixty years that data were available, the mean lamb marking value (70%) for Moble was reasonably high, although variability was a major problem (Table 4.14, Figure 4.6). The shire lamb marking by comparison was less variable than Moble, with a lower long-term mean.

In terms of nutrition of the breeding ewe (and therefore lamb survival), the first critical period is just prior to joining as the ewe needs to be in sufficient condition for cycling to take place. However, cycling and

Table 4.14 Descriptive statistics of Moble and Quilpie shire lamb marking.

Statistic	Moble lamb marking[1] (%)	Quilpie shire lamb marking[2] (%)
Mean	70	54
Standard deviation	20	14
CV	29	25
Minimum	9	19
Maximum	96	73

[1] Moble lamb marking statistics (1928–1995). Seven years of data within this period were not available. In one year (1965) ewes and rams were not joined, this year was not included in the above analysis.

[2] Quilpie shire lamb marking statistics (ABS 1952–1994).

conception are not usually an issue for ewes on Moble (B. H. Rutledge pers. comm.). Rather it is the third trimester of pregnancy and the period immediately after birth that are seen as more critical.

Figure 4.6 shows there was a slight but not significant ($P = 0.08$) increase in lamb marking percentages over time. Unjoined data points result from years where no information on lamb markings exists (except 1965 when no joining took place). Winter rainfall (Figure 4.7) was found to account for 15% ($P < 0.01$) of the variation in lamb marking. Similarly, Orr and Holmes (1984) reported that a relationship exists between winter rainfall, which results in the growth of ephemeral plant species (e.g. forbs), and lamb marking percentages. The evidence that Moble winter rainfall has increased (Figure 4.5) may be in part responsible for the observed slight increase in lamb markings over time. For a similar amount of winter rainfall (Figure 4.7), however, it can be seen that a large variation in lamb marking can still occur. There was no relationship found ($P > 0.05$) between summer rainfall and Moble lamb marking.

A number of years can be seen in Figure 4.6 where low lamb markings were recorded on Moble (e.g. 1928–29, 1945–46, 1951, 1961, 1979, 1991–92). Examples of extreme lambing events in the one decade were the 1960s years: 1960 (92%), 1961 (9%) and 1965 (ewes not joined). Buxton *et al.* (1999) commented that one south-west Queensland grazier considered it better to run ewes as a wether flock (unjoined) and to join them

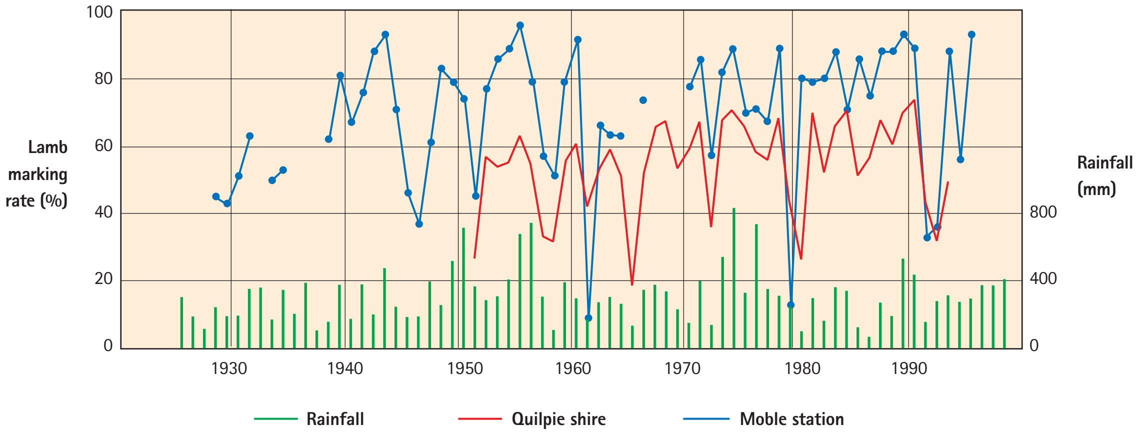

Figure 4.6 Lamb marking percentages for Moble (1928–1995) and Quilpie shire (ABS 1952–1994). Annual rainfall is for the 12 months September–August. Unconnected data points result from years where data on lamb markings were not available, or when ewes were not joined (1965).

only in optimal seasons for self-replacement purposes (e.g. ≈two in every five years). The following excerpt from the Moble shearing journal (February 1962) highlights the stress that climate placed on livestock management:

> No details of paddock percentage or average percentage (lambs) as sheep were all mixed up because of drought. These lambs (521 head, 9% lamb marking) were 1961 drop but were not marked until the above date owing to above mentioned drought (1961 drought).

The impact of low lamb marking years (1961 and 1965) can be seen in Table 4.12, where livestock numbers fell dramatically in subsequent years (1962, 28% and 1966, 41%). Livestock sales were not a major contributor to these reductions as they amounted to only 8 and 16% for 1961 and 1965 respectively.

Mortality

The effects of climate-related livestock mortalities (e.g. drought, flood and flystrike) on Moble are evident in historical information taken from the property's journals. While a comprehensive record of deaths was not available, some of these extreme events have been documented in earlier sections (Table 4.9). For example in 1996 Moble lost 1,000 young ewes when the property was in flood, emphasising that prediction of the next poor season owing to the erratic climatic conditions is still difficult even with the present advanced technologies. Other years when extreme mortalities occurred are shown in Table 4.13. In 'average' years on Moble it is expected that up to 7% of the total flock can be lost per year, including lambs (B. H. Rutledge pers. comm.).

4.3.8 Summary of stocking rate strategy and pasture management

Two major peaks (1928 and 1957) stand out in Moble's grazing history (Figure 4.2b). These peaks provide insight into the more general degradation episodes described in Chapter 2. The 1928 peak was early in property ownership that commenced in 1923. Wool prices peaked in early 1925, well above prices in the early 1920s (Figure 1.4, Payne and McLean 1939) and then collapsed by 50% in late 1925. Following relatively good seasons the extended drought of 1926 to 1930 was extensive through the sheep areas of eastern Australia and hence many graziers retained and fed stock (e.g. Lansdowne, Lilley 1973, Payne and McLean 1939). The 1957 peak followed a similar pattern in CPI-adjusted wool prices (Figure 1.5) with a peak in 1950 followed by a 40% decline to 1958. Unlike the previous peak the high stock numbers were supported by an excellent sequence of average and above-average years 1947 to 1957.

Thus the declining wool prices combined with drought in the late 1920s to increase grazing pressure and in some regions damaged the resource (Episode 2, Chapter 2). In contrast the 1950s price decline did not have the same impact on the pasture resource because of favourable rainfall. However, the sequence of good years in the 1950s appears to have established a wave of woody weed seedlings; this occurrence is still unproved due to a lack of recorded data (Episode 5, Chapter 2). At Moble severe fires occurred in the 1950s, but in other regions (e.g. Cobar–Byrock, Anon. 1969, Episode 5, Chapter 2) lack of fires was judged to have resulted in subsequent loss of production as revealed in the 1960s droughts.

In lower rainfall regions such as Quilpie, pastoral properties are susceptible to the distribution and intensity of rainfall throughout the year. Rainfall during the period examined was highly variable across the district and also within the property boundary itself. On the property itself the rainfall varied widely across paddocks, with comments often made (from the Moble rainfall book) concerning the fact that some creeks were running and others not.

It has been well documented throughout Moble's historical journals, and verified by the present managers, that the mulga resource has been a necessary part of livestock production. As the property is considered to

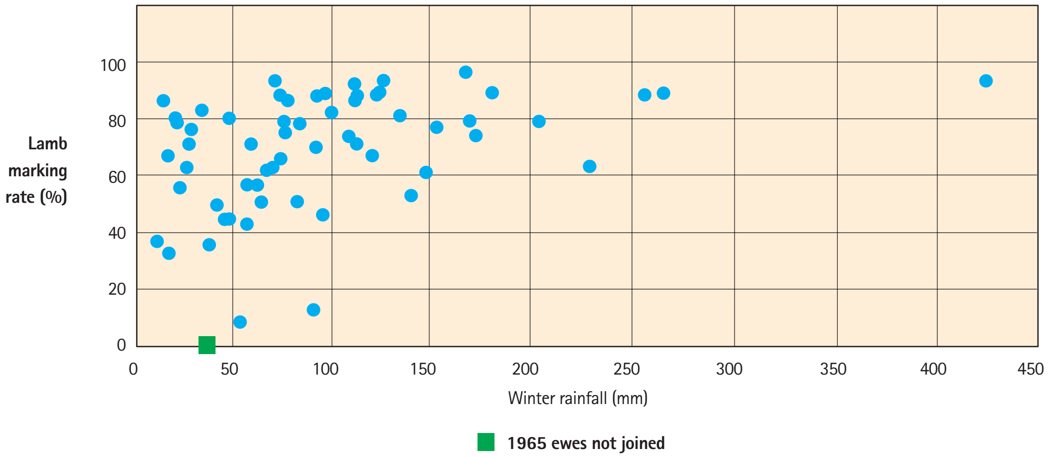

Figure 4.7 Moble lamb marking percentage compared with winter rainfall (1928–1995).

be in fair to good condition, it is regarded that the use of the mulga as a fodder resource has to some degree contributed to the present state.

With regard to tactical spelling, the total removal of domestic livestock from individual paddocks is not seen as an option. From experience in the last ≈20 years this action only results in native grazers (e.g. kangaroos) congregating and multiplying in the spelled area and thus the pasture is utilised all the same.

The utility of mulga as a fodder resource on Moble cannot be understated. Further, while animal mortality was severe on a number of occasions, flood events appeared to be as equally frequent and important as droughts. With respect to livestock production, constant natural increase in terms of high lamb markings was evident. The shearing at Moble for 1999 resulted in its highest wool yield (15,000 adult sheep and 5,000 lambs yielded 6.8 and 2.9 kg per head respectively). Moble's stability is attributed to the recognition of climate uncertainty and the resulting resource limitations. A balanced utilisation of the diverse mixture of country along with astute selling and management decisions have helped maintain its grazing capacity and pasture condition over the long term.

4.4 Management of climate variability on Lansdowne and Moble

The time series of annual property stock numbers and rainfall provide a rare opportunity to examine how the property managers of Lansdowne and Moble have managed for climatic variability over the last 70–100 years. As described in this section detailed and long-term livestock records provide information relevant to assessing resource sustainability by analysing property livestock numbers in terms of: (1) trends; (2) changes at the onset of drought; (3) response to extended drought; and (4) management during recovery.

4.4.1 Trends in stocking rate and rainfall

For both properties, over the whole period of records (>100 years for Lansdowne and 74 years for Moble) there were no statistically significant trends in stocking rate or annual rainfall. However, Lansdowne has had increasing stocking rates since the 1950s with the highest 10-year stocking rate in the 1990s (Figure 4.2a, Table 4.15). On a 10-year basis, Moble has had little variation in stocking rate (Figure 4.2b, Table 4.15) although rainfall had high year-to-year variability on both annual and decadal timescales.

The ratio of stock numbers to rainfall was examined for independent 10–year periods (starting 1887–1896 etc., Table 4.15). Lansdowne varied from a 'low' of 10.5 (DSE/km^2 per 100 mm/year) for 1947 to 1956 to a 'high' of 23.3 for 1987 to 1996 reflecting both the lower rainfall of the latter period and increased stock numbers, in some years 20–30% above the long-term mean. For Moble the ratio of stocking rate to decadal rainfall ranged from a low of 6.7 (DSE/km^2 per 100 mm/year) for 1947 to 1956 to a high of 11.8 for 1977 to 1986 reflecting the decadal variation in rainfall rather than any trend in stock-to-rainfall ratios.

Previous studies on grazing trials and 'safe' carrying capacities (Scanlan *et al.* 1994, McKeon *et al.* 1994) suggested that annual pasture utilisation should be below a 'safe' pasture utilisation threshold (e.g. 30% of summer growth) in 70–80% of years and hence the proportion of years that pasture recovery can occur substantially exceeds the time when pastures are overgrazed.

Accurate calculation of pasture growth averaged across a whole property requires detailed knowledge of property land types, landscape hydrology, tree densities and rainfall (Johnston 1996, p. 90). As this information is not readily available, we have used the general 'rainfall use efficiencies' corrected for location vapour pressure deficit (Johnston 1996) for the main land types of Lansdowne and Moble, i.e. 'downs' (2.76 kg/ha/mm) and 'mulga' (1.70 kg/ha/mm) to calculate annual pasture growth and utilisation. When the time series of stocking rates were expressed as pasture utilisation, both properties had over 70% of years less than a critical pasture utilisation threshold of 30%.

To classify historical years in terms of *drought* and *recovery* a sequence of decision rules has been constructed, based on the percentage deviation of annual rainfall from average (*%dev*). These rules aim to represent a 'commonsense' view of drought and recovery consistent with regional drought declaration and revocation (e.g. Day *et al.* 2003). A 30% deficiency in annual rainfall can substantially reduce pasture growth, potentially increase grazing pressure and starting *drought* conditions. Once in *drought*, above-average rainfall is required to end *drought* conditions and allow the recovery of pastures and livestock numbers to occur. *Recovery* can continue and be maintained under non-*drought* conditions even though rainfall is below-average. The annual periods were those most relevant to reported livestock numbers (January–December for Lansdowne, September to August for Moble).

Thus the rules used to classify each historical year were:

1. *drought* starts when *%dev* was ≤–30 and the previous year was a non-*drought* year (i.e. first year of *drought*);
2. *drought* continues when *%dev* <0 (i.e. below-average rainfall) and the previous year was a *drought* year;
3. *recovery* begins when *%dev* ≥0 (i.e. above-average rainfall) and the previous year was a *drought* year (i.e. first year of *recovery*); and
4. *recovery* continues when *%dev* >–30 (below average to above-average rainfall) and the previous year was a non-*drought* year.

For Lansdowne over 108 years (commencing in 1890) there were 15 '*drought* starts' and a total of 34 years in *drought* (31%). For Moble over 72 years (commencing in 1925) there were 14 '*drought* starts' and a total of 26 years in *drought* (36%).

These percentages are similar to the proportion of time that the Local Government Areas have been officially 'Drought Declared' (Daly 1994). For the period 1964 to 1989 Daly (1994, p123) reported that Tambo and Quilpie shires were declared 29% and 38%, repectively. Whilst the proportions of years classified as *drought* may appear high (30-40%), nevertheless they highlight that, in these semi-arid environments, graziers (and enterprises) have to manage for extreme rainfall deficiency and subsequent drought impacts in following years for a substantial proportion (>30% of years) of their working life.

Table 4.16 summarises stocking rate, change in stocking rate from the previous year, rainfall and the ratio of stock-to-rainfall for each year-type. For both properties the initial drought periods faced by the properties were not included in the analysis and the property history suggests that these years were 'learning experiences' (1885 and 1888 for Lansdowne and 1926 to 1930 for Moble; Figure 4.2a,b). The second year of recovery (R2) after the above *drought* periods was chosen as the 'start' year for the results discussed in Table 4.16. For Lansdowne these periods were 1890 to 1997 (108 years) and 1932 to 1996 for Moble (65 years).

For Lansdowne the composite of the 15 'first year of *drought*' (Table 4.16) had low rainfall (average of 44% below mean) yet there was little change in stocking rate from the previous year (average decrease of 2%). As described above, livestock were fed at Lansdowne during the droughts of 1926/27, late 1934 to mid 1935, and April to mid December 1965. The years 1926, 1934 and 1965 were classified 'first of year of *drought*' in sequences that lasted 2 to 3 years. In the second year of the *drought* sequence rainfall deficiency was less severe (average of 25% below mean) but stock numbers were lower (–16%) with an average annual decrease from the previous year of 10%. When *drought* conditions ended, the initial two years of *recovery* had an average rainfall 15% above the mean, but stocking rate was still 10–19% below the long-term mean even though stocking rate had increased on average from the previous year (average increase of 6% per year). For *recovery* periods five to ten years after each *drought* sequence, stocking rates were on average 9–21% above the long-term mean.

Analysis for Moble was similar to Lansdowne but, as would be expected with perennial mulga available as a feed source, there was less impact of the first year of *drought* on stock numbers and stocking rate change from the previous year. Compared to the first year of *drought*, stocking rate was lower in subsequent *drought* years and the first year of *recovery* (10% and 14% below long-term mean). For Moble, stocking rates were reduced by 10% on average in the first year of *recovery*.

For Moble the first drought experience (1926–1930) was undoubtedly a difficult one as it also was for many graziers (and animals) across eastern Australia. The 1926–1930 drought occurred in combination with

Table 4.15 Decadal variability in stocking rate (DSE/ha), average annual rainfall (mm/year) and ratios of stocking to rainfall for Lansdowne and Moble. Ratio of stocking rate to decadal rainfall was calculated as DSE/km^2 per 100 mm/year.

Decade	DSE/ha	Lansdowne mean annual rainfall	Ratio stock to rainfall	DSE/ha	Moble mean annual rainfall	Ratio stock to rainfall
1887–1896	0.89					
1897–1906	0.69	446	15.6			
1907–1916	0.93	474	19.6			
1917–1926	1.01	547	18.6			
1927–1936	0.74	448	16.6	0.27	264	10.4
1937–1946	0.76	441	17.2	0.26	256	10.1
1947–1956	0.65	620	10.5	0.32	474	6.7
1957–1966	0.86	500	17.2	0.31	272	11.5
1967–1976	0.89	443	20.2	0.30	414	7.4
1977–1986	0.88	479	18.5	0.29	245	11.8
1987–1996	1.04	449	23.3	0.29	319	8.9

collapsing wool prices (1925, 1929) and many graziers retained and fed stock in the hope of better prices (Payne and McLean 1939). As a result the stocking rate response to drought was different to the average pattern. The above decision rules for classifying years suggest that drought conditions lasted from 1926 to 1930. Stocking rate increased on Moble during this period to peak in 1928 at 45%, well above the subsequent long-term stocking mean (Figure 4.2b). Continuing drought conditions in 1929 led to a halving of stock numbers to 22% below the long-term mean. There was a small increase in 1930. Short-term recovery in rainfall occurred in 1931 and 1932 with further reductions in stocking rate but the onset of drought conditions again in 1933 led to a sharp decline in stocking rate to 27% below the long-term mean.

In the description of Episode 7 in (1960s – south east Queensland, Chapter 2) W.H. Burrows indicated that the use of mulga as a drought feed resulted in animals being retained at the break of drought (and any 'false' breaks to drought). High grazing pressure at the time of pasture recovery reduces the potential for perennial grasses to re-establish. The analysis for Moble (Table 4.16) indicates that the stocking rate was lower in the first year of recovery (–14% below long-term mean) and the ratio of stock-to-rainfall was the lowest for any of the year-types in the 'drought/recovery' cycle. Thus on average, the use of mulga at Moble has not led to increased grazing pressure at the time of recovery.

Table 4.16 Average of stocking rate and rainfall variables for different year-types in the drought/recovery cycle:

D1 first year of drought (rainfall ≤70% of mean)
D2 second year of drought (rainfall < long-term mean)
D3 etc. subsequent years of drought (rainfall < long-term mean)
R1 first year of recovery after drought (rainfall ≥ long-term mean)
R2 second year of recovery (rainfall ≥70% of mean)
R3 etc. subsequent years of recovery (rainfall ≥70% of mean)

Year type in drought cycle	Number of years	% deviation of annual rainfall from long-term mean	Rainfall (mm)	Stocking rate (DSE/ha)	% deviation of stocking rate from long-term mean	% change in stocking rate from previous year	Ratio of stocking rate to annual rainfall (DSE/km^2 per 100 mm/year)
Lansdowne							
D1	15	-44	281	0.82	-7	-2	29.8
D2	10	-25	374	0.71	-16	-10	19.6
D3-5	9	-33	334	0.74	-14	-4	22.3
R1	15	16	580	0.78	-10	6	13.7
R2	10	15	576	0.70	-19	6	12.3
R3-4	16	15	576	0.85	-1	3	17.0
R5-6	12	18	592	0.94	10	4	17.0
R7-8	10	2	511	1.04	21	4	21.0
R9-12	11	1	508	0.93	9	-1	19.6
Moble							
D1	13	-51	158	0.29	1	1	19.5
D2-3	8	-35	210	0.26	-10	-4	14.8
R1	13	28	410	0.25	-14	-10	6.1
R2	9	21	387	0.27	-5	8	8.0
R3-4	10	28	410	0.30	5	10	8.7
R5-11	12	21	389	0.36	24	7	10.0

The above analysis of the 'average' drought/recovery cycle indicates that:

1. over most droughts the properties were able to withstand severe rainfall deficiency in the first year of drought;
2. reduction in stocking rate occurred in subsequent drought years;
3. stocking rates remained below the long-term mean in the first years of recovery resulting in relatively lower grazing pressure; and
4. stocking rates exceeded the long-term mean only when the properties were well into the recovery period.

Thus the apparent success of both the properties as demonstrated by long-term maintenance of carrying capacity has involved the successful management of the drought/recovery cycle allowing appropriate response to drought and reduced grazing pressure at the time of recovery.

4.5 Conclusion

The information presented in the analyses shows the value that historical property data and stock records can provide. Immense hardships induced by drought and flood have been borne by the livestock, the land and those people who have made a living from the pastoral industry in these areas. Relationships established between rainfall, stocking rate, livestock production, and management activities over long periods can account for changes in land resources and the subsequent productivity.

Should the activity of analysing historical grazing records continue? A number of things need to be considered:

1. the opportunity to verify and clarify much of the recorded information is disappearing due to the age of the generation who have lived through these historical events (in 2001 the median age of Australian farmers and graziers was 51, ABS 2003); and
2. properties that have comprehensive records of management and activities are likely to represent the most efficient operators within the industry.

The properties that have been examined here have been quoted as being in 'fair to good' condition in terms of their respective pasture and resource base. While generalisations cannot be made, it is likely that enterprises that endeavour to document the progress of their activities over time also have the wherewithal to interpret and adapt/adopt management decisions that prove optimal and sustainable for both enterprise and land resource.

The accounts of Moble and Lansdowne stations given throughout this chapter have presented a view of climate events in the south-west and central-west of Queensland. The analyses have given an insight of how two properties have managed over time to maintain their place in today's pastoral industry. The aim of these accounts was to present the property data and anecdotal information in a comprehensive format that encompasses a climatic episode, how it affected the livestock, management and land resource, along with additional scientific material that may enhance our understanding. It is concluded that the properties' management had in fact 'learnt from history' over time with respect to highly variable climate and economic environments.

The Future

The aim of this report was to understand the causes of major episodes of degradation and recovery in Australia's pastoral rangelands, so that the community might better prepare for the future. A dominant feature of the eight episodes studied was the severe and extended nature of the drought periods. However, from our review, we concluded that other non-climatic factors contributed to the observed degradation. In some cases, the drought period revealed the damage already done in terms of the loss of desirable perennial vegetation (grasses and shrubs) and surface soil protection. This damage was the result of the over-expectation, by some graziers and governments, of the stocking rate that the resource could carry both in and out of drought. To some extent this over-expectation was falsely reinforced by relatively short periods (approximately five years) of above-average rainfall. In some cases, rapid declines in commodity prices contributed to the economic pressure to stock with too many animals.

The property histories highlighted that sustainable and profitable use of the rangelands is possible. However, the histories also documented the difficulties encountered during the first experience of severe and extended drought. These histories raised the question - does every new owner or manager have to learn from the painful experience of over-expectation of carrying capacity? The challenge for rangeland science is to provide and communicate the knowledge gained from hard-won grazier experience, and the understanding emerging from climate and ecological research. The episodes described here indicate that such knowledge is as important as skills in pasture management, animal husbandry and financial management.

Over the last decade, projects in cooperation with the grazing industry have addressed (and are continuing to address) the issue of sustainable grazing management and the extrapolation of successful grazier experience (e.g. Johnston *et al.* 2000). However, there remain major information and knowledge gaps that will have to be addressed if we are to prevent the next degradation episode. Systems for monitoring rangeland condition especially vegetation and soil cover are being put in place so as to provide 'near real-time' resource assessment and alerts of increased risk of degradation. However, our review indicates that prevention of degradation will require a more timely reduction in numbers of livestock and other herbivores based on better risk assessment of the likelihood of extended drought periods. Our review of the current understanding of climate drivers of rangeland rainfall (and temperature) provided a tantalising glimmer of what might be possible at longer time scales (e.g. Power *et al.* 1999, White *et al*. 2003) than the current three-monthly outlooks.

The rapid growth in knowledge in climate science, fuelled in part by a desperate race to understand current climate trends and anticipate the impacts of future climate change, has not yet been regarded as mature enough to be included in operational climate forecasting systems for rangeland regions. Hence research to improve mechanistic understanding, skill and lead time are high priorities. Nevertheless, the initial understanding of El Niño-Southern Oscillation and other factors (e.g. Indian Ocean sea surface temperatures) has underpinned current operational forecasting systems and community understanding since the late 1980s. The continuing use and availability of knowledge of historical climate variability and climate forecasts at least challenges graziers, their advisers, and governments to better manage for future climate variability to avoid repeating the mistakes of the past.

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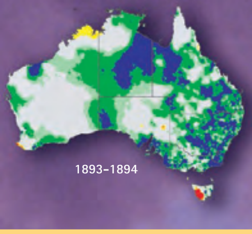
Guide to Acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AE	Adult Equivalent
AMLC	Australian Meat and Livestock Corporation
APGR	Annual Population Growth Rate
AussieGRASS	Australian Grassland and Rangeland Assessment by Spatial Simulation
AWC	Australian Wool Corporation
BAE	Bureau of Agricultural Economics
BoM	Bureau of Meteorology
BPC	Burdekin Project Committee
BPES	Burdekin Project Ecological Study
BW	Body weight
C_3 plants	Plants with the C_3 pathway of photosynthesis (most broad-leaved plants and temperate grasses)
C_4 plants	Plants with the C_4 pathway of photosynthesis (many tropical grasses)
CFA	Cast for age
CFW	Clean Fleece Weight
CINRS	Climate Impacts and Natural Resource Systems - a group within Natural Resource Sciences, Queensland Department of Natural Resources, Mines and Energy
CO_2	Carbon dioxide
CPI	Consumer Price Index
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Coefficient of variation
%dev	Percent deviation
DEHCD	Department of Environment, Housing and Community Development
DSE	Dry Sheep Equivalent
DVR	Dust Visibility Reduction
DW	Dressed weight
E/W	East/west
ECOSSAT	Ecological studies in the semi-arid tropics (A CSIRO program)
ENSO	El Niño – Southern Oscillation
GBC	Grass basal cover
GHG	Greenhouse gas
GIS	Geographic Information System
IOCI	Indian Ocean Climate Initiative
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
KVR	Koonamore Vegetation Reserve
ln	Natural logarithm
MLA	Meat and Livestock Australia
MSLP	Mean Sea Level Pressure
N/S	North/south
NRM&E	Queensland Department of Natural Resources, Mines and Energy
NWCB	Northwest Cloudbands
PDO	Pacific Decadal Oscillation
PPD	Pastures Protection District
QCCA	Queensland Centre for Climate Applications
QDPI&F	Queensland Department of Primary Industries and Fisheries
SILO	Project providing enhanced agrometeorological datasets for Australia
SOI	Southern Oscillation Index
SPCZ	South Pacific Convergence Zone
spp	Species
SR	Stocking rate
SST	Sea Surface Temperature
WARLUS	Western Arid Region Land Use Study
WARMS	Western Australian Rangeland Monitoring System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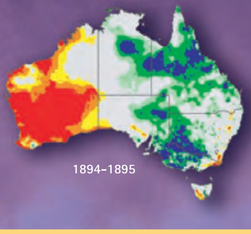
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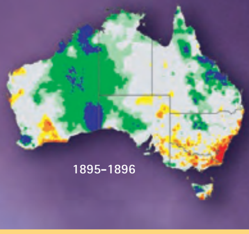
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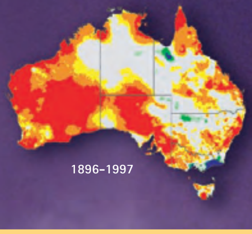
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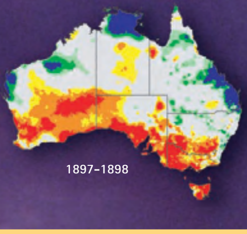
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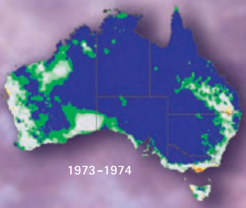
IN AUSTRALIA'S RANGELANDS

Learning from History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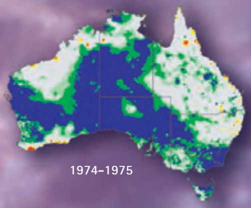
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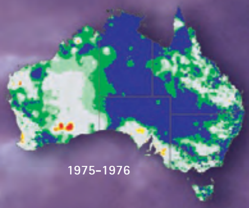
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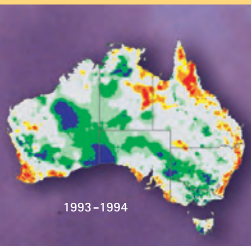
Queensland Government
Natural Resources, Mines and Energy

Australian Government
Australian Greenhouse Office

CVAP
Climate Variability in Agriculture R&D Program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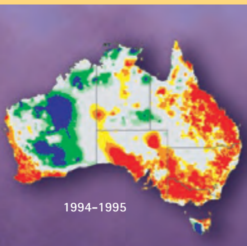
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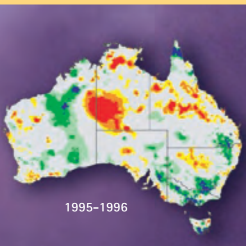
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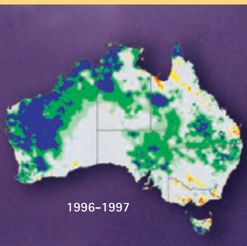
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