THE UNIVERSITY OF QUEENSLAND

AUSTRALIA

Degraded or just dusty?:
150 years of ecological change in inland eastern Australia

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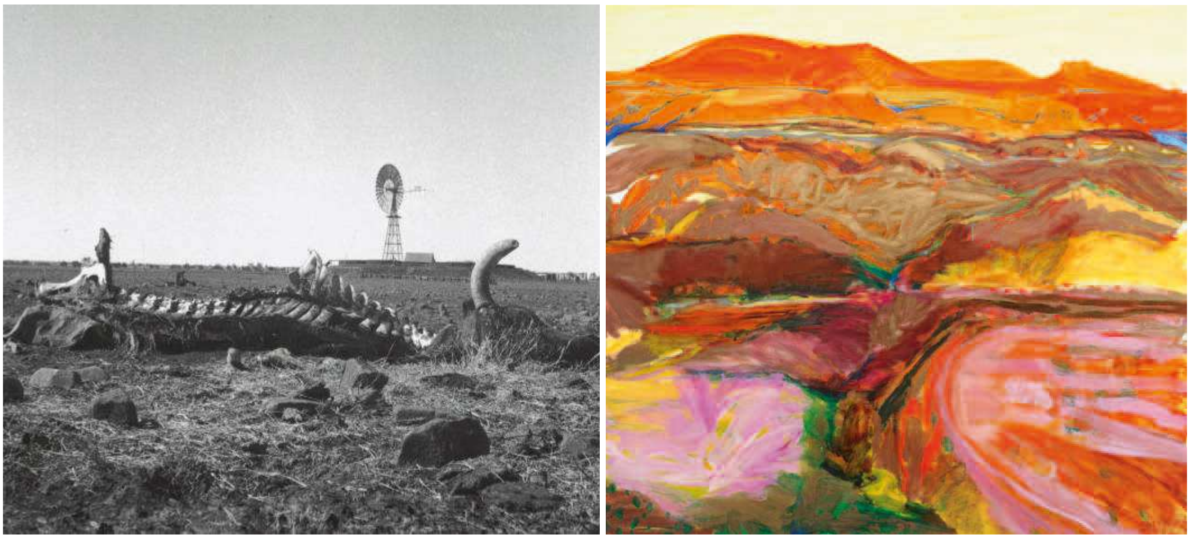
B. Environmental Management (Natural Systems & Wildlife) (Honours class I)

A thesis submitted for the degree of Doctor of Philosophy at

The University of Queensland (2014)

School of Biological Sciences



'Remains of cow near a windmill, western Queensland', Sidney Nolan (1952), part of Nolan's drought series commissioned by *The Courier Mail* (National Library of Australia) *(left)*. 'Mirrica Botanical (The Desert Garden)', Jo Bertini (2012), part of the 'Desert Garden' collection depicting the eastern Simpson Desert blooming after exceptional summer rains *(right)*

ABSTRACT

The ecological history of rangelands is often presented as a tale of devastation, where fragile drylands are irreversibly degraded through inappropriate land-use. There is confusion about how to recognise and measure degradation, especially in low productivity environments characterised by extreme natural variability and where abrupt management upheavals mean that there are few reference sites. These issues have important consequences for rangeland development and management programs, many of which are founded on a perception of serious and ongoing degradation from a former 'natural' state. In this thesis, I employ three approaches to assess degradation in inland eastern Australia, part of one of the largest desert landforms in the world and subject to recurring arguments about the cause and magnitude of landscape change since pastoral settlement 150 years ago: written historical records, grazing exclosures, and identification and surveys of rare and potentially sensitive elements of the flora.

From the 1840s, the journals of European explorers provide the first written descriptions of inland Australia. In Chapter 2, I use this record to test prevailing paradigms relating to five key themes of environmental change: vegetation structure, fire regimes, waterhole permanence, macropod abundance and medium-sized mammal assemblages. 4500 observations from fourteen journals spanning twelve expeditions between 1844 and 1919 were geo-referenced. Careful evaluation of the record suggests little change in broad vegetation structure or waterhole permanence, running counter to prevailing paradigms. The sparse observations of fire suggest burning was infrequent, while macropods were apparently uncommon in semi-arid areas where they are abundant today. Systematic evaluation of the explorer record for a region can provide ecological insights that are difficult to obtain by other means. However, there are limitations inherent in the historical record and findings are necessarily broad.

In Chapter 3, I use long-term grazing exclosures to examine the impacts of cattle grazing on two widespread vegetation types. We measured herbaceous biomass and plant species richness and abundance at five 14-year-old exclosures in north-eastern South Australia. We did not detect any significant differences between grazed and ungrazed treatments in total species richness or abundance, life form richness or abundance, or herbaceous biomass. The dominance of ephemeral species confers resilience by limiting the development of strong feedbacks between grazing intensity and vegetation dynamics, meaning that the non-equilibrium paradigm best describes this grazing system. This chapter forms part of a series of three studies using exclosures to examine grazing impacts across three biogeographic regions.

Exclosures encompass only a tiny area, meaning that rare or grazing-sensitive species may not be represented, or may have become locally extinct prior to the erection of exclosures. In Chapter 4, I identify rare and potentially sensitive elements of the western Queensland flora through a systematic examination of herbarium records and expert interviews. Five threat syndromes were identified, arising from the interaction of plant biology and threatening processes, and 60 potentially threatened species had been overlooked in the listing process. However, lack of data on distribution, abundance, population dynamics and threats precluded robust conservation assessments for most species. In particular, detecting genuine rarity and decline was confounded by extreme temporal variability, low collection effort spread over a vast area and poor understanding of threatening processes.

Chapter 5 examines patterns of rarity in the flora of a semi-arid mountain range, the Grey Range, with a high concentration of rare species and 150 years of elevated grazing pressure. Habitat specialisation, reproductive biology and biogeographic history interact to create observed patterns of rarity, and there is no evidence that any species have become rare or restricted as a result of grazing. Species confined to barren plateaux, sheltered habitats and gidgee toeslopes represent relictual populations, and the association of rare plants with larger plateaux suggests local extinctions were more probable on smaller plateaux during Pleistocene climatic fluctuations.

Chapter 6 presents the results of four years of targeted surveys for the candidate species identified in Chapter 4. Search effort and survey results were used to assess 91 species against international Red List criteria. One-third of species were widespread and abundant at least in certain seasons but had appeared rare due to sparse collections. The conservation status of 20 species, mostly newly-recognised species from restricted habitats, was upgraded and 14 remained listed due to having restricted areas of occupancy. The IUCN criterion that allows for listing of species due to extreme fluctuations (in combination with restricted and fragmented populations) is not justified for arid zones, where these fluctuations may actually confer resilience to grazing for short-lived forbs and geophytes. With the exception of 12 artesian spring species, continuing declines were documented for just six species.

In Chapter 7, I bring together my results and those of previous studies to provide a critical evaluation of the extent and magnitude of ecological change in inland eastern Australia. There is no evidence of unidirectional change in vegetation structure, irreversible degradation or loss of plant species, although some palatable species have declined at a landscape scale. It is apparent that some prevailing paradigms have become entrenched despite lack of empirical evidence. However, many medium-sized mammals have declined dramatically or become extinct since European settlement, while large macropod numbers have increased in the semi-arid zone. Management actions and areas requiring further research are discussed. The approach presented here, incorporating the historical record, comparison of sites with different management histories and targeted surveys for rare and potentially sensitive species, can be used to assess degradation in drylands with abrupt changes in management and contentious ecological narratives.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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<u>Publications during candidature</u>

Peer-reviewed papers forming part of thesis

(See below for details of contributions for each paper.)

Silcock, J.L., Piddocke, T.P. & Fensham, R.J. 2013, 'Illuminating the dawn of pastoralism: evaluating the record of European explorers to inform landscape change', *Biological Conservation* 159:321-331.

Silcock, J.L. & Fensham, R.J. 2012, 'Arid vegetation in disequilibrium with livestock grazing: evidence from long-term exclosures', *Austral Ecology* 38:57-65.

Silcock, J.L., Fensham, R.J. & Martin, T.G. 2011, 'Assessing rarity and threat in an arid-zone flora', *Australian Journal of Botany*, 59:336-350.

Silcock, J.L. & Fensham, R.J. 2014, 'Specialised and stranded: habitat specialisation and biogeographic history determine the rarity of species in a semi-arid mountain range', *Journal of Biogeography*, 41:2332-2343.

Silcock, J.L. & Fensham, R.J. 2015, 'Lost in time and space: re-assessment of conservation status in an arid-zone flora through targeted field survey', *Australian Journal of Botany* (accepted December 2014).

Peer-reviewed papers not forming part of thesis

Fensham, R.J., Silcock, J.L. & Dwyer, J.M. 2011, 'Plant species richness responses to grazing protection and degradation history in a low productivity landscape', *Journal of Vegetation Science* 22:997-1008.

Fensham, R.J., Silcock, J.L., Kerezsy, A. & Ponder, W. 2011, 'Four desert waters: setting arid zone wetland conservation priorities through understanding patterns of endemism', *Biological Conservation* 144:2459-2467.

Silcock, J.L., Tischler, M. & Smith, M.A. 2012, 'Quantifying the Mulligan River pituri, *Duboisia hopwoodii* (F.Muell.)F.Muell. (Solanaceae) trade of central Australia', *Ethnobotany Research and Applications* 10:37-44.

Powell, O.C., Silcock, J.L. & Fensham, R.J. 2013, ‘Oases to oblivion: the rapid demise of springs in the south-eastern Great Artesian Basin, Australia’, *Groundwater* (published online 18 December 2013).

Fensham, R.J., Silcock J.L. & Firn, J. 2014, ‘Managed livestock grazing is compatible with the maintenance of plant diversity in semi-desert grasslands’, *Ecological Applications* 24:503-17.

Book chapters

Silcock, J.L. (in press), ‘Waterways: people and water in the Lake Eyre Basin’, Chapter for booklet to accompany Aboriginal map of Lake Eyre Basin produced by Lake Eyre Basin Ministerial Forum & Northern Territory Department of Land Resource Management.

Conference abstracts and presentations

Silcock, J.L., Fensham, R.J. & Martin, T.G. 2011, ‘Assessing rarity and threat in an arid zone flora’, Ecological Society of Australia Conference, 21-25 November, Hobart.

Silcock, J.L. 2013, ‘Lost in time and space?: Reassessment of rarity and threat in a desert flora’, presentation to Australian Rivers Institute, Griffith University, 4 October 2013.

Silcock, J.L. 2014, ‘Australian desert springs’, presentation at ‘Living with springs: Groundwater conservation, ecology and environmental change in arid landscapes’ workshop, 21-22 March, Siwa Oasis, Egypt.

Magazine articles

Silcock, J.L. & Fensham, R.J. 2013, ‘Degraded or just dusty?’, RIPRAP Magazine, Edition 36: 34-36.

Silcock, J.L. 2014, ‘Specialised and stranded: rare plants in the Grey Range’, *Wildlife Australia Magazine* 51 (Autumn): 22-25.

Silcock, J.L. 2014, 'Illuminating the dawn of pastoralism', *Wildlife Australia Magazine* 54 (Summer): 9-13.

Publications included in this thesis

Five collaborative papers are reproduced in entirety as chapters forming part of this thesis, although Abstracts, Acknowledgements and Reference Lists have been consolidated and some material which was included as supplementary material when published has been moved to the main text. Because each study (with the exception of Chapters 4 and 6) focuses on a slightly different area, I have retained the study area descriptions in the Methods of each Chapter, as well as providing a broad overview in the Introduction. Contributions to the chapters are as follows:

1. Silcock, J.L., Piddocke, T.P. & Fensham, R.J. 2013, 'Illuminating the dawn of pastoralism: evaluating the record of European explorers to inform landscape change', *Biological Conservation* 159:321-331.

   Original body of paper written by JS, with input and reworking from RF. Three-quarters of the geo-referencing work was done by TP, and one-quarter by JS. Analysis and mapping done by JS.

2. Silcock, J.L. & Fensham, R.J. 2012, 'Arid vegetation in disequilibrium with livestock grazing: evidence from long-term exclosures', *Austral Ecology* 38:57-65.

   Study design, field work and plant identification by JS and RF. Analysis done by JS with assistance from RF and John Dwyer. Paper written by JS, with input from RF.

3. Silcock, J.L., Fensham, R.J. & Martin, T.G. 2011, 'Assessing rarity and threat in an arid-zone flora', *Australian Journal of Botany*, 59:336-350.

   Writing, analysis, mapping and field work by JS with editorial advice and reworking of manuscript from RF and TM.

4. Silcock, J.L. & Fensham, R.J. 2014, ‘Specialised and stranded: habitat specialisation and biogeographic history determine rarity of species in a semi-arid mountain range’, *Journal of Biogeography*, 41:2332-2343.

   Study designed by JS with input from RF. Field work, plant identification, soil analysis and data analysis done by JS with assistance from Don Butler. Manuscript written by JS with editing and input from RF.

5. Silcock, J.L. & Fensham, R.J. 2015, ‘Lost in time and space: re-assessment of conservation status in an arid-zone flora through targeted field survey’, *Australian Journal of Botany* (accepted December 2014).

   Field work, plant identification, mapping, analysis and writing done by JS, with editorial advice from RF.

<u>Contributions by others to the thesis</u>

As outlined above.

<u>Statement of parts of the thesis submitted to qualify for the award of another degree</u>

None.

Acknowledgements

The past four years have passed in a haze of red dust and campfire smoke, stony hills and claypan mirages. Throughout, the generosity, wisdom and humour of family, friends and colleagues have remained constant.

My parents, Alastair and Jane Silcock, have provided unfailing love and support over 30 years, inspiring my interest in the Australian bush with visits to less-frequented tourist destinations including bush cemeteries, observatories, information centres and overgrown nature reserves. My late Pa, Ray Offner, would have been amazed at the places I visited during my field work and very proud of this thesis. My Nanna, Margaret Offner, has followed these adventures from her comfy chair with varying degrees of horror but unfailing interest – I guess the dreads can come off now Nanna! And my sisters Robyn and Clare, who welcomed me into their spare room when I came to town with my dirty swag, accumulated dust and general chaos.

My peripatetic lifestyle over the past few years would not have been possible without the generosity of friends who opened their houses to me, providing homes rather than just places to stay between trips, accepting my sporadic arrivals and departures and not infrequently chasing me down the road with forgotten necessities. First and foremost, Tracy Wattz and Peter McRae in Charleville, on whose verandah much of this thesis was written and many ideas debated, and who I feel lucky to count as a second family. Also Rod Fensham and Esther Haskell, Cam and Yumi Kilgour and Rebecca and Toby Piddocke in Brisbane, the Kerezsy family out on the Peninsula, Alicia Whittington and Jo King in Longreach then Karratha, Tim Hunt at Millstream, Maree Winter (who never failed to provide a potted social history of western Queensland over dinner) and Vol and Robyn Norris in Longreach, Rosie Kerr at Idalia, Dan McKellar at Currawinya and Eulo, Russell Fairfax and Bill and Maggi Scattini in the mountains of abundance and Max Tischler down the coast.

Rod Fensham, as supervisor and friend, has provided inspiration and entertainment in equal measure, and this thesis owes much to his ideas, knowledge, enthusiasm and unparalleled persistence. He assisted with field work, shared stories and speculations around the campfire, edited and improved drafts and curtailed my tendency to verbosity. Tara Martin, while we were rarely in the same place, provided guidance and comments.

Many people participated enthusiastically in plant hunts, enduring long hours of fruitless wandering punctuated by infrequent bouts of great excitement: Tracy Wattz, Peter McRae, Rod Fensham, Maree Rich, Ingrid Elmitt, Andrew Harper and the camels, crew and cobs of Australian Desert Expeditions, Jennifer Firn, Jeremy Drimer, Max Tischler, Martin Denny, Clare, Alastair and Jane Silcock, Alicia Whittington, Jimmy Wilson, Joel de Souza, Steve Peck, Josie Fraser, Dan & Jake McKellar and four years of students and volunteers on UQ's Outback Ecology Field Course, ably coordinated by the unflappable Selena Hobbs. Others sat patiently – and not so patiently – in the car, notably Adam Kerezsy, whose love of stony ridges in summer is palpable, and Terry 'park the car in the shade' Beutel. Rosie Kerr, ranger and all-round wonder woman, relished showing me huge populations of my 'rare' plants in the wild stony hills and ran numerous errands for me well above the call of duty. Along with Gimme Walter, she led a team of willing fencers from the University of Queensland IROOS to establish my *Xerothamnella* exclosures: Cody, Erin, Lauren, Simone and Bec, your presence lives on in the enchanted forest!

Botanists at the Queensland Herbarium have assisted generously with plant identification over the years, and shared their knowledge of threatened species, especially Megan Thomas, John Thomson, Paul Forster, Ron Booth, Dan Kelman, Gordon Guymer, David Halford, Ailsa Holland and Tony Bean, who continues to inspire with his amazing botanical eye and passion for rare species. Don Butler suggested the title for this thesis and was always on hand to provide sage advice on analysis, interpretation and writing. Many others kept an eye out for, collected and shared observations of rare plant species, including Maree Rich, Jenny Milson, Rebecca McPhee, Kerry Whiddett, Angus Emmott, Peter McRae, Tracy Wattz, Col Dollery, David Albrecht, Dan Duval, Neville Walsh, Bob Parsons, Paul Foreman, Russell Fairfax, Steve Peck, Alicia Whittington, Manda Page and David Orr.

Thanks to colleagues and friends at the Department of Primary Industries in Longreach, where my rare plant odyssey began, especially Terry Beutel and David Phelps for allowing me time on work trips to search for some lost species and Jenny Milson who has always shared excitement in my plant hunts and discoveries. Richard Silcock let me use his trusty germination cabinet at Boggo Road, helped with its operation and shared long-term observations of western Queensland vegetation. Queensland Parks & Wildlife staff in Charleville, Longreach and various National Parks assisted with accommodation, vehicles and field work, especially Peter McRae, Tracy Wattz, David Akers, Maree Rich, Alicia

Whittington, Chris Crafter, Steve Peck, Dan McKellar, Mark and Jenny Handley, and Andy Coward. Teresa Eyre, Martin Denny, Alicia Whittington, Steve Peck, George Madani, Peter McRae, Max Tischler and Toby Piddocke shared unpublished data and opinions on rarely-seen and potentially declining or threatened fauna. Jo Bertini generously allowed her painting of the Simpson Desert blooming to grace my title page, while John Dwyer's statistical and sartorial prowess were appreciated throughout.

This PhD was funded by an Australian Postgraduate Award and CSRIO Flagship Scholarship. The assistance of the University of Queensland Biological Sciences finances team in sorting out strange and lost receipts and explaining the system is gratefully acknowledged, especially Carol Pomfret, Scott Tucker, Lyn Lin, Marie Walker and Gail Walter. My attendance at the Ecological Society of Australia conference in Hobart in 2010 was supported by a Student Travel Grant.

Geo-referencing of the explorer journals was funded by South Australian Arid Lands Natural Resource Management group and administered by Henry Mancini. David Kaus of the National Museum of Australia provided the transcript of the journals of Basedow and Greenfell Thomas, while Richard Neville of the Mitchell Library granted permission to quote from the transcripts. Alice Yeates geo-referenced the journal of Mitchell. Rosemary Niehus, Dale Richter and Jack Kelley provided GIS assistance. Discussions with Max Tischler, Peter Connelly and Owen Powell were useful in clarifying the routes of Hodgkinson, Winnecke, Kennedy and Landsborough. Martin Denny generously provided his data and shared ideas on the interpretation of the explorer record from western New South Wales. Many landholders and local residents shared their knowledge of the present-day permanence of waterholes. Suggestions from Mark Burgman and three anonymous reviewers greatly improved the clarity and structure of the manuscript.

The Innamincka exclosures study was funded by South Australian Arid Lands NRM. The encouragement and assistance of Greg Campbell of S. Kidman & Co Ltd, who provided us with exclosure locations, background information, stocking rates and rabbit information, allowed us to undertake this study. We also thank Graham and Maree Morton of Innamincka Station for their assistance. Peter McRae provided a vehicle for field work, and shared his long-term knowledge of grazing in the Channel Country. Chris Crafter shared the results of her rabbit surveys and general knowledge of the area. John Maconochie provided information on stocking rates in the South Australian arid zone. John Dwyer and Don Butler assisted with the analysis. The Grey Range field work was assisted by a student grant from the Queensland Wildlife Preservation Society. Comments from Michael Bull (Innamincka) and Neil Gibson (Grey Range) and anonymous reviewers improved and clarified both manuscripts.

Landholders and managers across western Queensland shared their wealth of observations about country, discussed changes and theories around the kitchen table and provided access, directions, meals, vehicle repairs, tours to interesting and out-of-the-way spots and even much-needed clothing on occasion: Margaret Pegler, Wendy and Peter Sheehan (Trinidad), Jim & Bec Scott (Milo), Bill and Barbara Scott (Thylungra), Julie and Bill Scott (Budgerygar), Judy and Dougal Atkinson (Lisburne), Rick and Jen Keogh (Amaroo), Angus and Karen Emmott (Noonbah), Simon and Christine Campbell (Norwood), Dick O'Connell and Robyn Pulman (Wombula), Bean and Kathy Schmidt (Wallen), Neil and Barbara Marks (Ambathala), Ian and Cheryl Allen (Highlands), Stuart and Pauline Scott (Mt Calder), Vinnie and Jenny Richardson (Leopardwood Park), Ian Feather (Cowley), Keith Shepherd (Mogera), Ian Walker (Ravensbourne), Sonia and Peter Doyle (Forest Hill), Graham Moffatt (Camoola Park), Chris and Waddy Campbell (Mt Windsor), Rob Murphy (Prairie Flat), Sandy Kidd (Ourdel), Graeme Pfitzner (Werewilka), Randall Newsham (Bundoona), John and Helen Lynch (Viola Downs), Ian Campbell (Rifle Creek), Harry Chambers (Glenelg), Ian Beale (Dunheved), Bob Morrish (Springfield), Denise and Steve Hawe (Spring Plains), Richard Agar (Myendetta), Alicia Hoch (The Springs), Alan and Fay Wills (Edgbaston), Ian and Kerri Halstead (Naryilco), Greg and Toni Sherwin (Kilcowera/Zenoni), Carolyn and Dale Chicken (Mt Marlow), Les Thomas at the Yaraka pub, Moc and Sheree Parker in Hungerford, Ian Pike in Eulo and Cujo in Aramac. I also acknowledge the traditional owners of the country I have travelled over and come to call home. There is nowhere one can walk in the inland without being reminded of their long and intimate association with country.

Finally, I am indebted to the countless field trips, long drives and verandah/fireside/riverbank/pub conversations over the years which have helped shape my ideas about deserts, ecology and much else besides. Thanks especially to Rod Fensham, Peter McRae, Tracy Wattz, Adam Kerezsy, Max Tischler, Russell Fairfax, Owen Powell, Jeremy Drimer, Alicia Whittington, Martin Denny, Clare Silcock, Terry Beutel, Manda Page, Toby Piddocke, Rebecca Piddocke and Al Healy.

Keywords

Degradation, rangelands, arid, explorers, vegetation change, grazing, rarity, threat

Australian and New Zealand Standard Research Classifications (ANZSRC)

ANZSRC code: 050202, Conservation and Biodiversity, 33%

ANZSRC code: 050102, Ecosystem Function, 33%

ANZSRC code: 210303, Natural Resource Management, 33%

Fields of Research (FoR) Classification

FoR code: 0602 Ecology, 50%

FoR code: 0502 Environmental Science and Management, 40%

FoR code: 2103 Historical Studies, 10%

‘To me the monotonous variety of this interminable scrub has a charm of its own; so grave, subdued, self-centred; so alien to the genial appeal of a more winsome landscape, or the assertive grandeur of mountain and gorge. To me this wayward diversity of spontaneous plant life bespeaks an unconfined, ungauged potentiality of resource; it unveils an ideographic prophecy, painted by Nature in her Impressionist mood, to be deciphered aright only by those willing to discern through the crudeness of dawn a promise of majestic day. Eucalypt, conifer, mimosa; tree, shrub, heath, in endless diversity and exuberance…Faithfully and lovingly interpreted, what is the latent meaning of it all? ...The mind retires from such speculation, unsatisfied but impressed.’
(Joseph Furphy, *Such Is Life…being certain extracts from the diary of Tom Collins*, 1944)

‘Do you go much into your country?’ asked Voss, who had found some conviction to lean upon. ‘Not really, not often’ said Laura Trevelyan…. ‘A pity that you huddle,’ said the German. ‘Your country is of great subtlety.’
(Patrick White, *Voss*, 1957).

‘It is a continent of dreams we inhabit, a waiting continent. All those who have set foot in its bush, in its lonely places, know that silence. The continent is dreaming.’
(David Ireland, *A Woman of the Future*, 1979)

‘I walked out into the thick red wind. It was like swimming under water, in a flooding river. Dust sifted into my lungs; I was drowning. And the bell, up on the hill, kept tolling. Purposeless, moved by the wind. There was no town, no hill, no landscape. There was nothing. Only myself, swimming through the red flood, that had covered the world…I have seen rain in Tourmaline. Can you believe that? How can you? You have not seen that green, that green like burning, that covers all the stones of the red earth, and glows gently, upward, till the grey-green leaves of the myall are drab no longer, but green as the grass, washed in reflected light. And the fragrance then; the turpentine weed, the balm. Birds in the air; sheep in the far green distance. And pools, lakes, oceans of blowing flowers.’
(Randolph Stow, *Tourmaline*, 1963)

Table of Contents

List of Figures

List of Tables

List of Abbreviations used in thesis

CE: Critically Endangered
CHC: Channel Country biogeographic region
E: Endangered
GAB: Great Artesian Basin
km: kilometres
LC: Least Concern
LEB: Lake Eyre Basin
mm: millimetres
MGD: Mitchell Grass Downs biogeographic region
MUL/ML: Mulga lands biogeographic
NT: Near Threatened
NWH: North West Highlands biogeographic region
NSW: New South Wales
NT: Northern Territory
QLD: Queensland
SA: South Australia
V: Vulnerable

CHAPTER 1.

INTRODUCTION

The ecological history of rangelands globally is often presented as a tale of destruction and devastation. 'Degradation narratives' involving undesirable environmental change and productivity declines date from the earliest dryland civilisations. Archaeological excavations and ancient records show that salinisation and silting began to affect Lower Mesopotamian irrigation schemes from about 2400 B.C., ultimately playing an important part in the demise of Sumerian civilisation (Jacobsen and Adams 1958). Abandonment of Khorezm oasis settlements in Uzbekistan in the first century A.D. (Thomas and Middleton 1994) and Roman settlements in north African and Arabian deserts around 500 A.D. (Pyatt *et al.* 1999; Barker 2002) have also been attributed to environmental destruction. The perception that rangelands surrounding the Mediterranean were degraded was expressed by Plato in 400 B.C., who described the hills around Athens as being '…like the skeleton of an old man, all the fat and soft earth wasted away and only the bare framework of the land being left' (Sinclair and Sinclair 2010:117).

From the1830s, the prevailing French colonial narrative in northern Africa blamed Arab pastoralists for desertification and deforestation (Davis 2004; 2005). In the seminal *Man and Nature* (1864), George Perkins Marsh proclaimed 'I am convinced that forests would soon cover many parts of the Arabian and African deserts, if man and domestic animals…were banished from them' (Marsh 1965:117). In the southern hemisphere, Europeans had inhabited inland Australia for less than four decades when concerns about rangeland degradation spawned the 1901 New South Wales Royal Commission (Noble 1997; Griffiths 2001). However, it was the western American 'Dust Bowl' of the 1930s that swept arid lands degradation to the forefront of popular imagination and reverberated through a generation of scientific thinking (Worster 1979; Schubert *et al.* 2004). The 1930s also saw early scientific investigations of land degradation in Africa, with (Stebbing 1935; 1938), a European forester who visited Africa, describing the encroachment of the Sahara southwards into the Sahelian savannah as 'one of the most silent menaces of the world'.

Four decades later, events in the Sahel thrust dryland degradation to the forefront of the global environmental agenda. The 'Great Sahelian Drought' of 1968-73 followed a long period of colonial rule, which had disrupted traditional food production systems at a time of increasing populations. Modern communications technology allowed pictures of mass starvation and suffering to be beamed into western living rooms and stimulated international concern (Thomas and Middleton 1994). In the drought aftermath, an assessment of environmental conditions in northern Sudan reported that the Sahara had encroached 100 km south into semi-desert scrub in the two decades since its boundary was originally mapped (Lamprey 1988, cited in Dodd 1994).

As with events in inland eastern Australia and on the North American plains, drought was viewed as the catalyst which had exposed harmful effects of overgrazing, inappropriate cultivation and deforestation. The Sahelian disaster was seen as a vivid expression of the global problem of desert expansion, and led to the convening of a United Nations Conference on Desertification in Nairobi in 1977. Through the 1970s and 80s, the United Nations Environment Program (UNEP) made a series of dramatic public announcements and assessments of the extent of the problem, assisted by a willing media, for example:

> 'At a rate of 27 million hectares lost a year to the desert or to zero economic productivity, in a little less than 200 years at the current rate there will not be a single, fully productive hectare of land on earth' (UNEP Desertification Control Program Activity Centre 1987:17, quoted by Thomas & Middleton 1994).

In terms of capturing the world's imagination, desertification was the first 'big' environmental issue, preceding the ozone hole, acid rain and global warming in its adoption by the popular and pseudo-scientific press and policy makers, and its appeal to growing environmental concerns (Thomas & Middleton 1994). Today, the emblematic image conjured by the term remains one of rampaging deserts smothering villages and destroying farmland and pasture, resulting in a man-made famine among subsistence farmers and significant losses of productivity beyond (Binns 1990; Nater *et al.* 2008; Imeson 2012). Indeed, dust storms are among the most enduring and powerful images of dryland degradation, immortalised by Woody Guthrie and portrayed by generations of musicians, artists, poets and novelists (Lorentz 1936; Steinbeck 1939; Guthrie 1940;

Stow 1963; Chambers 2010). Other evocative symbols of degradation have also become axiomatic: barren earth strewn with bleached animal carcasses, erosion scars, eerily twisted trees, crumbling relics and the lonely tenants of a broken land (Figure 1-1).

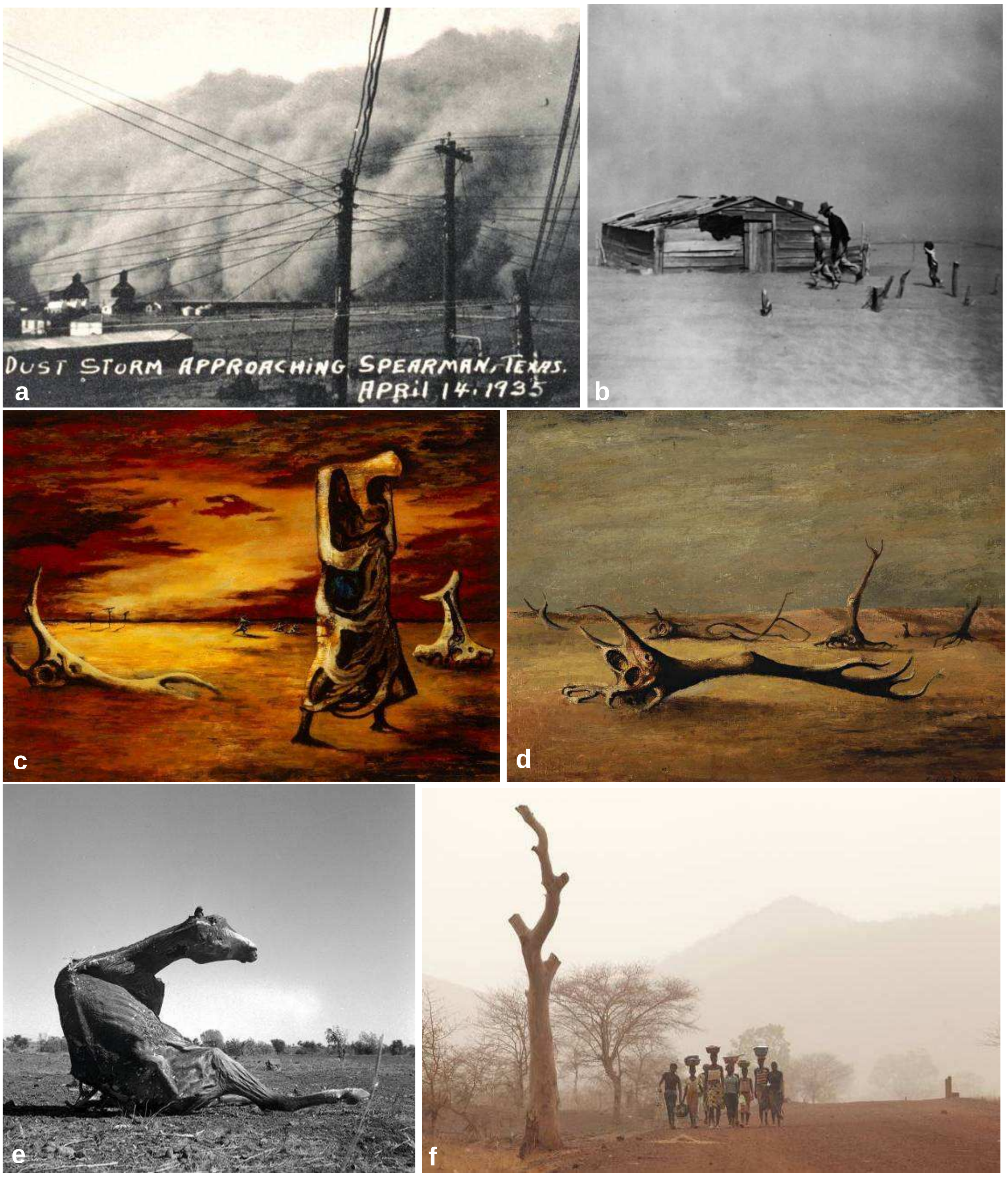


Figure 1-1. Archetypal degradation images: **(a)** Dust storm approaching Spearman, Texas, April 14 1935; **(b)** Farmer and sons walking in the face of a dust storm, Cimarron County, Oklahoma, April 1936 (US National Oceanic and Atmospheric Administration); **(c)** Russell Drysdale 'Crucifixion' (1946) and **(d)** 'Western Landscape' (1945), based on sketches made for *The Sydney Morning Herald* during drought in New South Wales (Art Gallery of NSW) **(e)** Sidney Nolan 'Untitled' (1952), part of a series of drought photographs taken on the Birdsville Track, originally commissioned by *The Courier Mail*, who ultimately deemed them too graphic to publish (National Library of Australia); **(f)** On the move through the dry dusty landscape in Burkina Faso, African Sahel (Andy Hall/Oxfam)

Dryland degradation: themes and examples

A central tenet of degradation narratives is that rangelands are inherently fragile and vulnerable to exploitation, particularly during dry times and with the imposition of management regimes which diverge from their evolutionary history. In the Americas and Australia, this involves the imposition of European 'ranch style' pastoralism since the 1830s (Heathcote 1983; Aagesen 2000). In recent decades, this form of pastoralism has spread to some areas formerly utilised on a nomadic basis or not grazed at all such as the Horn of Africa and Kalahari Plains (Perkins and Thomas 1993; Thomas and Middleton 1994). In African, Arabian and Central Asian deserts, the upheavals associated with increasing populations, breakdown of traditional semi-nomadic or nomadic pastoral systems, encroachment of sedentary agriculture on traditional grazing lands, and in some areas restrictions on movements due to conflicts since the 1950s, are blamed for widespread degradation (Breman and Dewit 1983; Sinclair and Fryxell 1985; Bawden 1989; Tewari and Arya 2004; Verstraete *et al.* 2009).

The familiar symptoms of rangeland degradation transcend landscapes and management regimes. Vegetation is eaten down, palatable species especially perennial grasses become rare or are eliminated, long-lived species fail to regenerate, and the earth is left bare and unprotected (Sinclair and Fryxell 1985; Seymour *et al.* 2010; Slimani *et al.* 2010). Topsoil blows away or washes unimpeded into creeks, which become shallow and turbid (Khalaf and Alajmi 1993; Fanning 1999; Tongway *et al.* 2003; Gale and Haworth 2005). Removal of topsoil means irreversible loss of scarce nutrients, lowering of infiltration capacity and scalding (Mills *et al.* 1989; Miles 1993; van de Koppel *et al.* 1997; Okin *et al.* 2001). 'Weedy' species, often native or exotic shrubs or introduced grasses, increase rapidly to cover the bare ground (Noble 1997; Asner *et al.* 2003; Wilcox and Huang 2010; D'Odorico *et al.* 2012), while ecological processes such as water cycling and fire regimes are disrupted (van de Koppel *et al.* 2002; Ravi *et al.* 2009; Miller *et al.* 2010). Native fauna struggles to survive in these altered conditions, and introduced predators and/or human exploitation deliver the *coup de grace* (Morton 1990; Reid and Fleming 1992; Milton *et al.* 1994). Ultimately, entire ecosystems may undergo a change in state, at some point crossing a threshold beyond which they cannot recover (Westoby *et al.* 1989; Rietkerk *et al.* 1997; Asner *et al.* 2004; Browning and

Archer 2011). These ecological changes are accompanied by corresponding declines in agricultural productivity (Milton and Dean 1995; Aagesen 2000).

Maps of desertification, desertification risk and degradation essentially show all of the world's arid and semi-arid regions shaded with varying degrees of severity (Dregne 1983; Mabbutt 1984; UNCCD 2014). Peer-reviewed articles routinely report that 70% of all drylands are affected by desertification, a figure based on a heavily-questioned 1992 UNEP report (Verón *et al.* 2006). Some authors have suggested that degradation is an inevitable consequence of land-use in some arid environments (Caughley 1986; Beaumont 1993), a view encapsulated in the ancient proverb: *'Man strides over the earth, and deserts follow in his footsteps'* (in Worster 1979).

Some examples of arid lands degradation are well-documented and unequivocal, particularly the consequences of inappropriate dryland cultivation. The Dust Bowl conditions of the 1930s on the Great Plains of western North America were due primarily to rapid expansion of wheat cultivation on the Great Plains (Schubert *et al.* 2004) and dust storms remain a serious problem in parts of the United States, exacerbated by intensive grazing and clearing of vegetation for agriculture (Gouldie and Middleton 2006). The frequency and severity of dust storms has also been intensifed by land-use through eastern Russia, western Siberia and Kazakhstan (Kotlyakov 1991; Gouldie and Middleton 2006) and central Asia and China (Youlin *et al.* 2001). Desert water resources have borne the brunt of arid zone land-use in many regions. The shrinking of Lake Chad by 95% since the 1960s (Gao *et al.* 2011) and the desiccation of the Aral Sea since the 1950s to create a man-made desert known as Aralkum (Breckle *et al.* 2012; Loew *et al.* 2013) due to failed irrigation projects are well-known examples. The depletion of desert aquifers and loss of artesian springs has been documented globally (Idris 1996; Fairfax and Fensham 2002; Patten *et al.* 2008; Jiao 2010; Powell *et al.* 2013).

Shifts in plant species composition and abundance can indicate degradation, with palatable and perennial species typically replaced by unpalatable and annual species in grazed areas (Valone *et al.* 2002; Cingolani *et al.* 2003; Bartoleme et al. 2004; Díaz *et al.* 2007; Seymour *et al.* 2010). Palatable perennials can be particularly impacted by grazing during dry periods (Watson *et al.* 1997; Read 2004; Hacker *et al.* 2006), sometimes becoming locally extinct in more heavily grazed areas due to lack of recruitment (Tiver and Andrew 1997; Hunt 2001). Some rangelands have become degraded through invasion by exotic plants, especially where they change the structure and function of an ecosystem and have adverse affects on native species and/or agricultural productivity. The invasion of large areas of Mitchell grass downs by *Acacia nilotica* in Queensland (Spies and March 2004), *Prosopis* species incursion into arid and semi-arid rangelands globally (Muturi *et al.* 2013; Kumar and Mathur 2014) and invasion by exotic perennial grasses (Clarke *et al.* 2005; Brooks *et al.* 2010) are prime examples. Unpalatable native species may also increase at the expense of palatable species in grazed landscapes, creating a 'woody weed' problem with consequences for biodiversity, landscape function and production (Mack *et al.* 2000; Van Auken 2000; Roques *et al.* 2001; Graz 2008).

The combined effects of habitat modification, introduced predators, prey depletion and direct exploitation have led to extinctions and declines of many aridland fauna species globally over the past two centuries, providing clear examples of irreversible ecological damage. Large mammals have been especially susceptible to range contractions and extinctions (Cardillo *et al.* 2005), including carnivores and ungulates in North America (Laliberte and Ripple 2004; Stoner *et al.* 2013), numerous species of gazelle in Asian and African deserts (Saleh 1987; Baamrane *et al.* 2013; Li *et al.* 2013) and iconic species such as elephants and giraffes in African savannas (Ciofolo 1995; Bouche *et al.* 2011). The drastic demise of smaller mammals since pastoral settlement in Australia is well-documented (Johnson 2006; McKenzie *et al.* 2007), while large birds have also fared badly in many drylands (Goriup 1997; Thiollay 2006). Loss of fauna species may in turn affect ecosystem function, through changes in landscape processes, nutrient cycling and plant species composition (Branch *et al.* 1999; Noble *et al.* 2007; Waldram *et al.* 2008; Chillo and Ojeda 2012).

Questioning degradation narratives

These examples show that degradation has certainly occurred in some drylands, and is sometimes irreversible. However, perceptions that it is a universal and perhaps inevitable consequence of land-use in arid zones are simplistic and problematic. Where do they leave aridlands that have high background rates of wind and/or water erosion and inherently low or variable groundcover (Pickup 1989; Wiegand and Jeltsch 2000)? Particularly during drought, landscapes may display the hallmarks of degradation, but actually be able to recover rapidly after rain. Other landscapes appear 'degraded' most of the time, due to soil characteristics such as high salinity and/or sodicity and low and erratic rainfall (Dahlberg 2000b; Qadir and Schubert 2002). Annual plant cover in good times and bare ground during drought represent the 'healthy' state of many communities, rendering above-ground biomass or life-cycle traits poor indicators of degradation (Thomas *et al.* 1986; Blumler 1993). Even dust storms, the archetypal symbol of degradation, are natural occurrences in most aridlands and there is little evidence that dust production is associated with widespread land degradation (Brooks and Legrand 2000; Tegen *et al.* 2004; McTainsh *et al.* 2005). Moreover, the very low concentration of nutrients in the sandy soils predisposed to wind erosion means that even spectacular soil loss may have minimal impact in terms of nutrient depletion (Perkins and Thomas 1993).

Degradation narratives from northern Africa have been challenged since the 1930s. (Rodd 1938) spent years in Africa and questioned Stebbings' understanding, claiming that the boundaries of the Sahara had ebbed and flowed over time and cautioning against making judgements based on short-term observations in such a variable climate. Over the past three decades, numerous authors have questioned basic tenets underlying simplistic notions of degradation, particularly the 'myth of the marching desert' (Hellden 1988; Forse 1989; Binns 1990; Dodd 1994; Swift 1996; Thomas 1997; Verón *et al.* 2006). It is now widely accepted that the conclusions of Stebbings and Lamprey which became so influential were based largely on limited direct observation and uncorroborated information from local authorities. Contemporary research has demonstrated that the Sahara 'expands' and 'contracts' in concert with rainfall fluxes (Tucker *et al.* 1991; Herrmann *et al.* 2005).

Davis (2004) details how the narrative of decline and decay was constructed during the French colonial period in Algeria, Tunisia and Morocco. Founded on historical inaccuracies and environmental misunderstandings, it blamed 'hordes of Arab nomads and their rapacious herds' for deforestation and desertification of what was erroneously believed to have been a fertile forested landscape, and helped to justify Colonial policies aimed at restoring the region to its 'past glory'. Recent studies in southern African rangelands have found little evidence of degradation due to traditional communal herding practices and suggest that perceptions of degradation have more to do with ideology than evidence (Sullivan 1999; Dahlberg 2000a). The farming practices of indigenous people in North American drylands have been variously characterised as destructive or benign according to shifting colonial and post-colonial agendas (Minnis 2000). In northern African and Arabian deserts, the long-term dynamics of keystone *Acacia* species seem more complex than the oft-cited decline due to overharvesting and grazing (Rohner and Ward 1999; Lahav-Ginott *et al.* 2001; Noumi *et al.* 2010). Addison *et al.* (2012) document how perceptions of degradation have become entrenched in Mongolian rangelands despite not being supported by empirical evidence.

It is apparent that the magnitude and extent of rangeland degradation have often been exaggerated or misconstrued. In particular, quasi-apocalyptic images which have gripped the public imagination and remain prevalent in policy documents have mostly been discredited. Many clear examples of degradation involve fundamental modification of the landscape through irrigation, cropping and/or landclearing in marginal lands, or the extermination of individual species. The effects of extensive livestock grazing, which covers 25% of the global landsurface and is the single most extensive land-use (Asner *et al.* 2004), are more complex and contentious.

Recent research has highlighted the resilience of many rangelands to disturbance, including in the Middle East (Blumler 1998; Batanouny 2001), Mediterranean (Dell *et al.* 1986; Figueroa and Davy 1991; Perevolotsky and Seligman 1998), north America (Bestelmeyer *et al.* 2013) and Africa (Perkins and Thomas 1993; Oba *et al.* 2000), as well as the role of drought and other natural factors in desertification (Herrmann and Hutchinson 2005; Wang *et al.* 2008; UNEP 2011). The view that climate is the primary driver of vegetation dynamics in highly variable rangelands, with grazing playing a secondary role or even having little effect, has gained traction over the past two decades. Proponents of this non-equilibrium theory argue that the risk of degradation through overgrazing in such systems is limited, because the ephemeral forage is only abundant for brief, sporadic periods amidst frequent protracted drought, keeping livestock numbers well below the level where they can reach equilibrium with the vegetation community (Ellis and Swift 1988; Ward *et al.* 1998; Sullivan and Rohde 2002). Moreover, beneficial effects of grazing have been documented in some instances, including the promotion of tillering in grasses (Crawley 1987), improved germination of some perennial species (Reid and Ellis 1995; Rohner and Ward 1999) and control of shrub encroachment and invasive weeds (Popay and Field 1996; Perevolotsky and Seligman 1998). Rather than being universally viewed as a negative imposition, current theory predicts that the effects of long-term grazing on plant species diversity will be variable across ecosystems, depending upon evolutionary history, ecosystem productivity and herbivore type (Milchunas *et al.* 1988; Milchunas and Lauenroth 1993; Cingolani *et al.* 2005; Bakker *et al.* 2006).

Identifying and measuring degradation

In light of these divergent viewpoints and complexities, it is not surprising that confusion remains about how to recognise and measure degradation (Herrmann and Hutchinson 2005; Verón *et al.* 2006; Reynolds *et al.* 2011), despite considerable effort devoted to defining desertification and identifying indicators (Mabbutt 1986; Verstraete 1986). In particular, how can we distinguish characteristics inherent to aridlands from symptoms of anthropogenic degradation, especially in the face of extreme natural variability? These questions are more than theoretical semantics. Arid and semi-arid lands cover 40% of the global land surface and support over a third of the world's population, including many in the most economically vulnerable and politically unstable regions of the world (Reynolds *et al.* 2007; Nater *et al.* 2008). They are also a significant repository of global biodiversity (McNeely 2003; Durant *et al.* 2012; Brito *et al.* 2014).

Most rangeland development and management programs are founded on a perceived crisis of degradation and desertification; a perception that these systems have declined from a more pristine historical state (Fairhead and Leach 1995; Witt *et al.* 2000). Decades of work to arrest this decline have had little success in many parts of Africa, the Middle East and Asia (Goldschmidt 1981; Chatty 2001), and in some places have had unintended negative consequences (Davis 2005). Is it possible that at least some of this failure is due to misunderstandings or dubious interpretations of the ‘natural’ state and functioning of these systems, in the absence of a reference state (Sprugel 1991; Foster 2000)? Are these programs aiming for a desired state, an unattainable Eden, which never existed? Or, alternatively, are some systems so degraded that recovery is not possible, or occurs over such long timescales that results are not yet discernible? The implications of degradation narratives and their continued acceptance in public policy are profound, yet have rarely been explored systematically for individual areas.

Examining ecological change and degradation in inland eastern australia

In this thesis, I employ four approaches to assess ecological change and land degradation in a large semi-arid and arid area of inland eastern Australia, part of one of the largest desert systems in the world: the historical record; a network of long-term grazing exclosures; identification of and systematic surveys for potentially rare and sensitive elements of the flora; and assessment of water-remote areas and gradients in relation to rare plant occurrence.

Inland eastern Australia is loosely defined as that portion of Queensland, northern New South Wales, north-eastern South Australia and the eastern Northern Territory receiving <500 mm of average rainfall per annum. Average annual rainfall decreases on a south-westerly gradient from 500 mm along the eastern and north-eastern boundary of the study area to 120 mm in the Simpson Desert, but rainfall is highly variable both within and between years (Van Etten 2009; Morton *et al.* 2011). Summer temperatures are hot with maximums through December-February averaging 35-38°C and regularly exceeding 40°C, while short winters are characterised by cold nights (5-10°C), often falling below zero except in the northern quarter, and warm days averaging 20-27°C. Higher rainfall areas support *Acacia* and, to a lesser extent, *Eucalyptus* woodlands, while the more arid portions are dominated by gibber plains, rolling downs, wide floodplains, low-relief sandstone ranges, open shrublands dominated by *Acacia* species and extensive linear dunefields. The study area encompasses seven biogeographic regions: the Mulga Lands, Mitchell Grass Downs, Channel Country, Simpson-

Strzelecki Dunefields, Mt Isa Inlier, eastern half of the Desert Uplands and the southern portion of the Gulf Plains (Thackway and Cresswell 1995; Figure 1-2).

Aboriginal people have occupied inland Australia for at least 35 000 years, with populations expanding and retracting from coastal environments and refuges within the arid zone during climatic oscillations (Veth 1993; Smith 2013). Historically, the Australian desert had some of the lowest densities on record for human populations, although this varied substantially across ecosystems (Smith 2013). People adapted to aridity by being highly mobile, making opportunistic use of temporary water and food sources after rains and falling back on permanent waters as the country dried out (Holdaway *et al.* 2000; Simmons 2007). Aboriginal people influenced arid and semi-arid ecosystems through hunting, burning, manipulation of water sources, dispersal of plant propagules and deliberate sowing of some plant species (Hercus and Clarke 1986; Veth and Walsh 1988; Walsh 1990; Bandler 1995; Donaldson 2002; Wilson and Knight 2004). The nature and magnitude of some Aboriginal environmental impacts is contentious, particularly regarding fire regimes, megafauna extinctions and subsequent vegetation changes (Miller *et al.* 2005; Rule *et al.* 2012; Field *et al.* 2013; Prowse *et al.* 2014). However, it is clear that Aboriginal land management practices had a profound effect over millennia and in many ways created the landscape encountered by the first Europeans (Gammage 2011).

Europeans had been in Australia for over fifty years before a concerted attempt was made to explore the interior of the continent. The 1840 expedition of Edward John Eyre initiated two decades of exploration, which merged into a period of rapid pastoral settlement from the 1860s. By the 1890s, the pastoral frontier had enveloped nearly all suitable country across inland eastern Australia (see Chapter 2 for further details of pastoral settlement and exploration). Today, Australia has more land area under managed grazing than any other country (Asner *et al.* 2004). Most of the study area is used for extensive cattle and, in the eastern and southern portions, sheep grazing, with relatively small areas occupied by mining leases and conservation reserves. Large macropods occur across the area and are most abundant in semi-arid regions (Pople and Grigg 2001), with high densities of feral and, increasingly, semi-domestic goats in the Mulga Lands of Queensland and New South Wales (Southwell *et al.* 1993; Pople and Froese 2012). Rabbits were historically in plague proportions throughout large areas south of the Tropic of Capricorn, but have declined since the introduction of *myxomatosis* and *calici* virus in the 1950s and 1990s respectively, although they remain in high densities in some areas (Scanlan *et al.* 2006). Feral camels roam the Simpson-Strzelecki dunefields (Saalfeld and Edwards 2010) while horses, donkeys and pigs occur patchily throughout the study area (Edwards *et al.* 2004).

The introduction of domestic and feral herbivores represents the largest Holocene environmental change in inland Australia, which had supported relatively low densities of native macropods since the extinction of the Pleistocene megafauna ≈45 000 years ago (Pickard 1994; Johnson 2006; Fensham and Fairfax 2008). Since the 1901 New South Wales Royal Commission, much work has focused on ascertaining the impacts of this major land-use upheaval. However, the magnitude and causes of ecological change since pastoral settlement remain hotly debated, both in the scientific literature and the public sphere (Gill 2005). Substantial degradation of Australian rangelands over the past 150 years has been attributed to European land management practices (Gasteen 1982; Morton *et al.* 1995; White 1997; Letnic 2000; McKeon *et al.* 2004). Early accounts are especially stark, suggesting that initial impacts were both substantial and rapid, particularly during drought when over-optimistic stock numbers combined with rabbit plagues to destroy vegetation and leave the land exposed to wind and water erosion (Dixon 1892; Ratcliffe 1938; Tolcher 1986). Over a century of research and management programs have aimed to stem perceived declines in biodiversity, land condition and productivity. However, some scientists and long-term land managers argue that grazing is a sustainable land use with few adverse effects, particularly in perennial grasslands and on floodplains (Orr 1992; Phelps *et al.* 2007), or at least that changes are less pronounced, and ecosystems more resilient, than is commonly assumed (Mitchell 1991; Croft *et al.* 1997; Witt *et al.* 2006; Eldridge and Lunt 2010). Prevailing paradigms about landscape change are summarised in Chapter 2 and Appendix 2-1.

If areas of inland eastern Australia are ecologically degraded, I hypothesise that:

1. There will be clear evidence of landscape change in the historical record, particularly with regard to vegetation structure, landscape processes and relative abundance of native plant and animal species
2. There will be shifts in plant species composition and abundance under different management regimes, with palatable and perennial species replaced by unpalatable and annual species in grazed areas, and an overall decline in plant species diversity which will be particularly pronounced in low productivity ecosystems
3. The resulting lower groundcover, especially during drought, will lead to accelerated soil erosion, loss of nutrients and associated silting of creeks and waterbodies
4. Some plant and animal species will have become rare or disappeared from the landscape
5. Introduced species of plants and animals will have proliferated, changing ecosystem structure and function

Outline of thesis

Much of the contention regarding the magnitude of landscape change in inland eastern Australia stems from the rapidity of pastoral expansion and the lack of reference sites or studies predating this critical biogeographic watershed. The journals of European explorers from the 1840s are the first written descriptions of inland Australia, just prior to this major management upheaval. In **Chapter 2**, I employ this record to test six major hypotheses about landscape change, based on prevailing paradigms constructed from a synthesis of published material relating to five key themes of environmental change: vegetation structure, fire regimes, waterhole permanence, macropod abundance and medium-sized mammal assemblages. The explorer record provides a temporal perspective far exceeding that enabled by long-term field studies and facilitates unique insights that are impossible to gain through other methods. However, its interpretation invariably involves an element of conjecture and extrapolation, and any findings gleaned are necessarily broad. For example, explorer journals can provide information on vegetation structure but not the fate of individual plant species or lifeforms.

One way of examining finer-scale changes wrought by land management is through manipulation of management, or measurement of sites with different management histories. In grazed rangelands, many studies have used exclosures to recreate ungrazed 'reference areas'. In **Chapter 3**, I use five long-term grazing exclosures to examine the impacts of livestock grazing on two vegetation types in north-eastern South Australia. This chapter is part of a series of three studies which we have undertaken over the past five years, using established exclosures to examine vegetation changes in four widespread ecosystems: low dunefields and floodplains (Silcock and Fensham 2011, presented as Chapter 3), mulga forest (Fensham, Silcock and Dwyer 2010, Appendix 1-1) and Mitchell grassland (Fensham, Silcock and Firn 2014, Appendix 1-2).

While providing data on changes in species composition and abundance under grazing, the inherent and critical limitation of exclosures is that an ecosystem may have lost species or suffered irreversible soil degradation prior to livestock being excluded. Further, exclosures only cover a tiny fraction of an ecosystem, and rare or sensitive species may not be represented. A complementary method, then, is to identify rare and potentially sensitive species of the regional flora and conduct targeted surveys. In **Chapter 4**, I provide a framework for assessing rarity and threat in an arid zone flora. Through systematically assessing the status of all species known to occur in 635 300 km^2 of western Queensland using herbarium records and expert interviews, biases in the threatened species listing process and threat syndromes are identified, along with over 60 potentially threatened species that had been overlooked. However, lack of basic data on distribution, abundance, population dynamics and realistic threat syndromes precluded accurate IUCN Red List assessments for nearly all species. A major challenge for plant conservation in arid zones is distinguishing genuine rarity from low collection effort across vast areas and extreme temporal fluctuations in species abundance.

Chapter 5 examines causes of rarity in the flora of a semi-arid mountain range, the Grey Range, which was identified in Chapter 4 as having high concentrations of rare and potentially threatened species. Seven major habitats are characterised and 647 sites surveyed for 19 rare plants to establish the influence of habitat specialisation, species biology, biogeography and grazing pressure in determining patterns of distribution and abundance.

Chapter 6 presents the results of the systematic re-assessment of conservation status in the western Queensland flora, based on four years of targeted surveys for species identified as rare and potentially threatened in Chapter 4. Field data and search effort are used to assess ninety-one species against IUCN criteria. This approach facilitates robust conservation assessments across vast and poorly-known arid regions, distinguishing species that have merely been lost in space and time from those that may become lost from our landscape.

In **Chapter 7**, I bring together these studies, other literature from the study area and relevant theory to provide a critical exploration of the extent and magnitude of ecological change in inland eastern Australia. I assess each of the hypotheses put forward on pp.12-13 above against the available evidence, and discuss which are supported and which refuted by the evidence. Some aspects remain uncertain, and further research required to inform these questions is identified.

CHAPTER 2.

ILLUMINATING THE DAWN OF PASTORALISM: EVALUATING THE RECORD OF EUROPEAN EXPLORERS TO INFORM LANDSCAPE CHANGE

INTRODUCTION

Across rangelands in Australia and North America, where the spread of European pastoralism was omnipresent and abrupt, recurring arguments about the cause and magnitude of landscape change are frustrated by the rarity of records that predate this momentous biogeographic watershed (Swetnam *et al.* 1999; Witt *et al.* 2000; Goforth and Minnich 2007; MacDougall 2008). In the absence of reference sites unaffected by pastoralism, ecologists have turned to the historical record to better understand contemporary ecosystems and their dynamics (Swetnam *et al.* 1999; Foster 2000; Bowman 2001). Historical sources provide a temporal perspective far exceeding that enabled by long-term field studies, and are especially valuable where ecosystem alterations or upheavals predated formal studies (Jackson *et al.* 2001; Goforth and Minnich 2007; Luiz and Edwards 2011). Historical ecologists have employed a diverse array of sources spanning timescales from millennial to centennial and decadal, encompassing natural and documentary sources. The former include stratified sediments, pollen cores, deposits of material constructed by animals, tree-rings marking annual growth cycles and fire scars (see Swetnam *et al.* 1999 for examples). Documentary archives consist of written and visual records or historical landscapes, and are particularly powerful because they provide graphic imagery that resonates with a broad audience including non-scientists.

Interpretations of pre-pastoral landscapes from historical records are often used to support arguments about contemporary land management and conservation. Substantial degradation of Australian rangelands over the past 150 years has been attributed to European land management practices (Gasteen 1982; Marshall 1966; White 1997; Letnic 2000). Symptoms include soil erosion (Mills 1986; Fanning 1999; Gale and Haworth 2005) and associated silting of rivers and waterholes (Tolcher 1986; Pickard 1994), thickening of woody vegetation (Noble 1997; Rolls 1999;

Burrows 2002) and altered fire regimes (Russell-Smith *et al.* 2003; Gammage 2011). Changes in the composition and abundance of plant and animal species have also been flagged (Friedel *et al.* 2003; Landsberg *et al.* 2003; Woinarski and Fisher 2003), including a catastrophic decline of medium-sized mammals (Johnson 2006) and an increase in numbers of larger macropods in some areas (Newsome 1975). These issues, particularly soil erosion and changes in woody plant density, are common to arid lands globally (Archer 1989; Ayyad 2003; Reynolds *et al.* 2007). While many examples of environmental change are irrefutable, others are not supported by empirical evidence but have nevertheless become enshrined in the scientific literature and popular imagination as 'conventional wisdom' (Mitchell 1991). If the basis for these assumptions is unsound, attempts to understand these landscapes will be stymied and management misguided (Foster 2000).

Explorer journals provide the first written descriptions of inland Australia at a critical time just prior to an abrupt management upheaval. They have been used to reconstruct aspects of the pre-European landscape across Australia including: vegetation structure (Denny 1987; Ryan *et al.* 1995; Benson and Redpath 1997; Croft *et al.* 1997; Lunt 1998; Fensham 2008); fire regimes (Kimber 1983; Bowman and Brown 1986; Braithwaite 1991; Fensham 1997; Crowley and Garnett 2000; Vigilante 2001; Preece 2002; Gammage 2011); mammal declines (Kerle *et al.* 1992; Denny 1994; Lunney 2001); native species that are thought to have increased in range and abundance (Denny 1980; Barker and Caughley 1993; Auty 2004; Gammage 2010); and colonisation patterns of feral species (Griffin and Friedel 1985; Abbott 2002).

Given the absence of reference sites unaffected by changes associated with European land-use in arid and semi-arid eastern Australia, perceptions of widespread environmental change, and the relatively rich exploration history, a systematic examination of explorer journals for this area holds substantial potential for understanding landscape change. This paper examines the extent to which the observations of nineteenth and early twentieth century explorers can inform inferences about five key themes of environmental change: vegetation structure, fire regimes, waterhole permanence, medium-sized mammal assemblages and kangaroo numbers. Six prevailing hypotheses based on these themes were synthesised from the literature, and tested against the explorer record (Table 2-1).

Table 2-1. Prevailing paradigms and hypotheses tested using explorer record for five major themes (references are provided in Appendix 2-1)

Prevailing paradigm	Hypothesis tested	Conclusions and interpretation
There has been a general thickening of woody overstorey vegetation in the semi-arid zone of Queensland, especially *Acacia aneura* and *A.cambagei*	1. There will be numerous examples where explorers passed through open country that is now thickly wooded	Explorers passed through many areas of dense woodland and scrub, with no geo-referenced observations of open country now characterised by thick vegetation, refuting the paradigm of unidirectional vegetation change
(i) Fires are less frequent across the semi-arid zone, especially the mulga forests and Mitchell grasslands, due to lower biomass and active suppression (ii) In spinifex-dominated ecosystems, small, regular 'patchy' fires have been replaced by large, destructive wildfires following good seasons	2. Burning was regularly noted by explorers in areas where fire is uncommon today. 3. Burning was regularly noted in spinifex landscapes today characterised by infrequent large wildfires	Fire was rarely mentioned by explorers in the semi-arid zone, with the exception of Aboriginal burning of grasslands on the eastern edge of the semi-arid zone. Aboriginal burning in spinifex landscapes recorded by three explorers
Waterholes in some regions have 'silted up' since pastoral settlement due to the loss of groundcover and subsequent accelerated erosion, resulting in a decrease in depth and therefore permanence	4. Long-lasting waterholes were recorded by explorers in reaches where there are now no long-lasting waterholes	No change in permanence was evident from the explorer record for the majority of rivers and creeks.
The range and abundance of macropods have increased in semi-arid areas since pastoral settlement. Macropods were always abundant in wetter areas of eastern Australia prior to European settlement. Red kangaroo numbers fluctuate with seasons but have not changed greatly in the arid zone.	5. Few macropods were recorded by explorers in the semi-arid and arid zone, but they saw relatively large numbers in areas above 500 mm rainfall	Kangaroos were abundant in areas of >500mm, but there are very few references to macropods in semi-arid Queensland.
The range and abundance of medium-sized mammals have contracted across the study area.	6. Medium-sized mammals will be present in the explorer record in areas where they no longer occur	There are numerous explorer records of medium-sized mammals that are now locally extinct.

METHODS

Study area and exploration history

The study area is defined as the semi-arid and arid region of Queensland, and the adjacent arid zone of north-eastern South Australia and north-western New South Wales (Figure 2-1). Average annual rainfall decreases on a south-westerly gradient, from 500 mm in the north and east to just 100 mm in the Simpson Desert. Summer temperatures are hot with maximum temperatures throughout December-February averaging 35°C, while short winters are characterised by cold nights often falling below zero and warm days averaging 20°C (Bureau of Meteorology 2012). Higher rainfall areas support *Acacia* and, to a lesser extent, *Eucalyptus* woodlands, while the more arid portions are dominated by gibber plains, rolling downs, wide floodplains, low-relief sandstone ranges, open shrublands dominated by *Acacia* species and extensive linear dunefields.

Europeans had been in Australia for over fifty years before a concerted attempt was made to explore the interior of the continent. In 1840, Edward John Eyre was thwarted in his attempt to reach the centre of the continent by the chain of salt lakes which stretch through central South Australia. Exploration in western New South Wales, north-eastern South Australia and inland Queensland continued through the 1840s and 50s, with expeditions led by Captain Charles Sturt (in 1844-5), Major Thomas Mitchell (1845-6), Edmund Kennedy (1847), the ill-fated Ludwig Leichhardt (1848) and Augustus Gregory (1858). The 1860 Burke and Wills expedition spawned four 'recovery' expeditions in 1861-2, led by William Landsborough, Frederick Walker, John McKinlay and Alfred Howitt, all of which served the twin aim of assessing the pastoral potential of the inland.

Concomitantly, Governments in South Australia and Queensland were passing legislation designed to encourage settlement of the 'waste-lands', resulting in a period of rapid pastoral expansion. From the 1860s, pastoral settlement occurred alongside continued exploration. In 1862, when Landsborough travelled down the Flinders and Thomson Rivers to the Warrego, there were already occasional tracks of cattle along the streams. By the time Hodgkinson explored the Diamantina and Mulligan Rivers in the late 1870s, much of far western Queensland had been taken up by pioneer pastoralists, spreading into the area along the major rivers. The 1880s was a period of closer settlement, while surveyors such as Cornish, Poepell and Winnecke continued their explorations in the more arid areas to the west. Thus there were just 20 years between Eyre's expedition and the arrival of the first pastoralists. Within the next 30 years, the pastoral frontier had enveloped nearly all suitable country across inland eastern Australia.

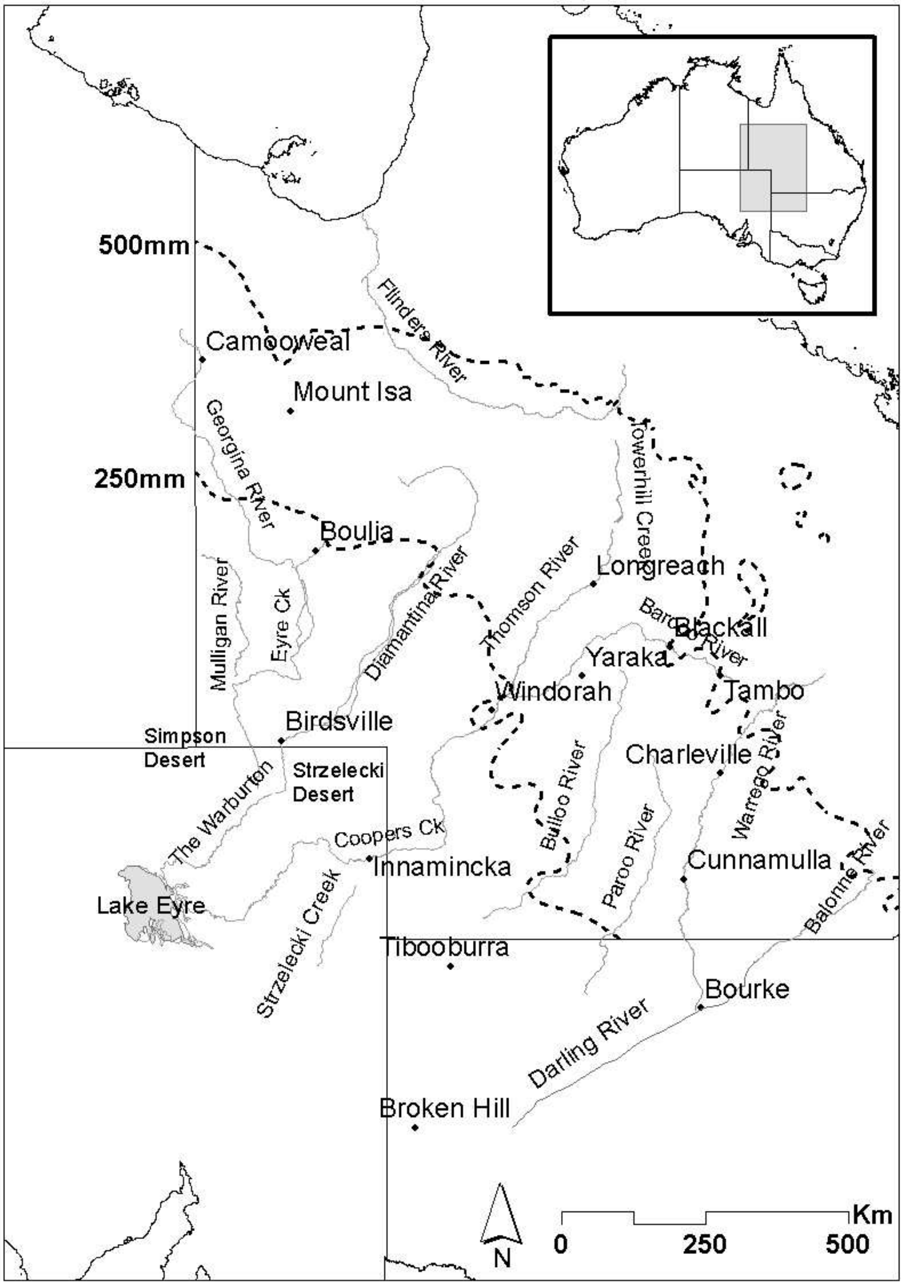


Figure 2-1. Explorers study area, showing 250mm and 500mm isohyets, major rivers, towns and regions mentioned in text

Journal selection and geo-referencing

Fourteen journals from twelve expeditions spanning the period 1844 to 1919 were examined for this study (Table 2-2). These journals were selected as they contain relatively detailed accounts of the country traversed, are able to be reliably geo-referenced and have all been published, albeit obscurely in some cases. Where selected explorers traversed country outside the semi-arid zone, these sections of the journals were also geo-referenced to inform interpretation.

Table 2-2. Explorer journals geo-referenced (observations do not include location clues; includes km of observation approximate only)

Explorer	Expedition	Year	Reference	Number of observations	Km travelled
Sturt	Expedition to Central Australia	1844-5	(Davis 2002)	683	2 690
Mitchell	Expedition into the Interior of Tropical Australia	1845-6	(Mitchell 1847)	846	2880
Kennedy + Turner	Expedition along the Rivers Victoria and Warrego	1847	(Beale 1983)	370 + 125 = 495	2 160
Gregory	Expedition in Search of Dr. Leichhardt and Party	1858	(Gregory 1884)	64	1 620
Landsborough	Expedition in search of Burke and Wills	1861-2	(Landsborough 1862)	505	2 230
Walker	Expedition in search of Burke and Wills	1861-2	(Walker 1863)	167	780
McKinlay	Expedition in search of Burke and Wills	1861-2	(McKinlay 1863)	280	1 880
Lewis	Lake Eyre Expedition Party	1874-5	(Lewis 1876)	284	1 280
Hodgkinson	North-West Explorations	1876-7	(Hodgkinson 1877)	320	1 620
Winnecke	Northern Exploration Party	1883	(Winnecke 1884)	294	2 160
Davidson	Assistant to Surveyor Twisden Bedford	1885	(Davidson 1920)	67	1 180
Basedow + Greenfell Thomas	Government North-West Expedition	1919	(Basedow 1919; Greenfell Thomas 1919)	475	1 420
TOTAL				*4480*	*21 900*

The route of each expedition was plotted in a Geographic Information System (ArcMap 9.3) based on distances, directions, latitude recordings and references to distinctive landmarks contained in the journals, supported by maps prepared by cartographers upon the explorers' return (Arrowsmith 1849; Harris and Loveday 1862). Latitudes were generally used only as secondary confirmation of location, since they were frequently subject to inaccuracy as a result of damage to instruments during travel (Gammage 1984; Denny 1987). Google Earth imagery and 1:250000 topographic maps were used as base maps, and the former proved particularly valuable for detecting geographic features mentioned by explorers. Knowledge of local aficionados, such as the location of marked trees and camps, was able to inform geo-referencing in some areas.

Observations and remarks were extracted from journals and geo-referenced. Five major types of observations emerged: 'people' (observations of, and interactions with, Aboriginal people), 'fire' (records of wildfire, smoke or past evidence of burning), 'vegetation' (from individual plant descriptions to descriptions of broad vegetation structure), 'fauna' (mammals, birds, reptiles, insects and molluscs) and 'water' (including rainfall, lack of water, permanence estimates and water quality). The 'people' category is not explored further in this paper, but provides a valuable anthropological reference for future work in the region.

Locations mentioned in the text are identified in Appendix 2-2. The spatial precision of each observation was recorded. 'Positive' locations were able to be pinpointed to within 1 km, usually where landmarks were referred to. 'Good' precision denotes accuracy to within a 3 km radius, 'reasonable' to within 10 km and 'tentative' to within a 30 km radius. In some cases, locations were difficult to assign, due to errors or omissions in explorer distances or bearings, or landforms not lining up with explorer descriptions. In such cases, we could not be confident of assigning a location to within a 30 km radius, and the precision is classed as 'poor'. For a small number of observations, locating the explorers with any degree of precision proved impossible, coordinates were not assigned and the observations were not used in further analysis. Where the process of identifying locations was complex, explanatory notes were included in the database. Where passages refer to observations made over sections of the journey, points were assigned to a mid-way point, and assigned a precision ranking as applicable. Two-thirds of all observations were able to be confidently geo-referenced to within 3 km, while 4% were classified as poor precision or unable to be geo-referenced at all.

Testing hypotheses

To aid in interpretation, we calculated the distance travelled by each explorer through 15 broad vegetation types, by intersecting explorer routes with broad vegetation groups as classified by the Queensland Herbarium (Table 2-3, Appendix 2-3). We then calculated the number of fire and macropod observations for each vegetation type and rainfall zone. The ecological interpretation in this paper is based on extensive contemporary travel and field studies between 1995 and 2012 and includes revisiting most of the sites discussed in the text, and over 300 interviews with long-term landholders and managers (Silcock 2009).

Table 2-3. Distances traversed by broad vegetation group and rainfall zone, with fire and macropod records per 1000 km (total number of records in brackets)

Vegetation type	Distance traversed (km)			Fire observations			Macropods observations		
	>500 mm	250-500mm	<250 Mm	>500 Mm	250-500mm	<250 mm	>500 Mm	250-500mm	<250 mm
Floodplain woodlands	205	940	175	9.8 (2)	1.1 (1)	5.7 (1)	4.9 (1)	0 (0)	0 (0)
Eucalypt woodlands	1090	240	0	9.0 (10)	0 (0)	-	3.7 (4)	0 (0)	-
Eucalypt-spinifex woodlands	50	490	0	0 (0)	2.0 (1)	-	0 (0)	4.1 (2)	-
Cypress	342	0	0	0 (0)	-	-	0 (0)	-	-
Mulga	70	600	130	0 (0)	0 (0)	0 (0)	14.3 (1)	4.1 (1)	0 (0)
Acacia on residuals	60	60	670	0 (0)	33.3 (2)	1.5 (1)	0 (0)	16.7 (1)	0 (0)
Brigalow	510	0	0	0 (0)	-	-	0 (0)	-	-
Gidgee	375	1230	330	0 (0)	0 (0)	0 (0)	0 (0)	0.8 (1)	0 (0)
Mixed woodland	190	140	0	10.5 (2)	0 (0)	-	0 (0)	0 (0)	-
Mitchell grassland	295	2790	450	6.8 (2)	0.7 (2)	0 (0)	10.2 (3)	0.7 (2)	2.2 (1)
Open forbland	0	630	3480	-	0 (0)	0 (0)	-	0 (0)	3.7 (13)
Spinifex dunes and sandpains	0	70	2810	-	28.5 (2)	0.7 (2)	-	0 (0)	0 (0)
Sandhills	0	0	1730	-	-	0 (0)	-	-	0.6 (1)
Wetlands	0	120	1620	-	8.3 (1)	0.6 (1)	-	0	1.2 (2)
Total	*3100*	*7400*	*11 400*	*5.2 (16)*	*1.2 (9)*	*0.4 (5)*	*2.9 (9)*	*0.9 (7)*	*1.5 (17)*

RESULTS AND DISCUSSION

A total of 4480 observations were geo-referenced from fourteen journals, covering over 21 000 km traversed in twelve expeditions (Figure 2-2). The majority of observations related to water (1905) and vegetation (2082). The former included rainfall and negative observations (i.e. lack of water), but included 290 references to permanence and 24 pertaining to springs, while the latter mostly comprised references to individual species (1060), vegetation structure (1035) and the abundance or shortage of grass (565). The journals contained 590 observations of animals, including 380 of birds, 105 mammals and 90 fish, and 62 references to fire. Fifteen broad vegetation groups were traversed, with most distance travelled through open forbland (4100 km), Mitchell (*Astrebla* spp.) grassland (3450 km) and spinifex (*Triodia* spp.) dunes and sandplains (2860 km). Over 1000 km of non-spinifex sandhills, wetlands, gidgee (*Acacia cambagei* and *A. georginae*) and *Eucalyptus*-dominated woodlands were traversed, with 800 km travelled through mulga (*Acacia aneura*)-dominated communities. The following sections present six hypotheses based on prevailing paradigms, which are tested using the explorer record (Table 2-1).

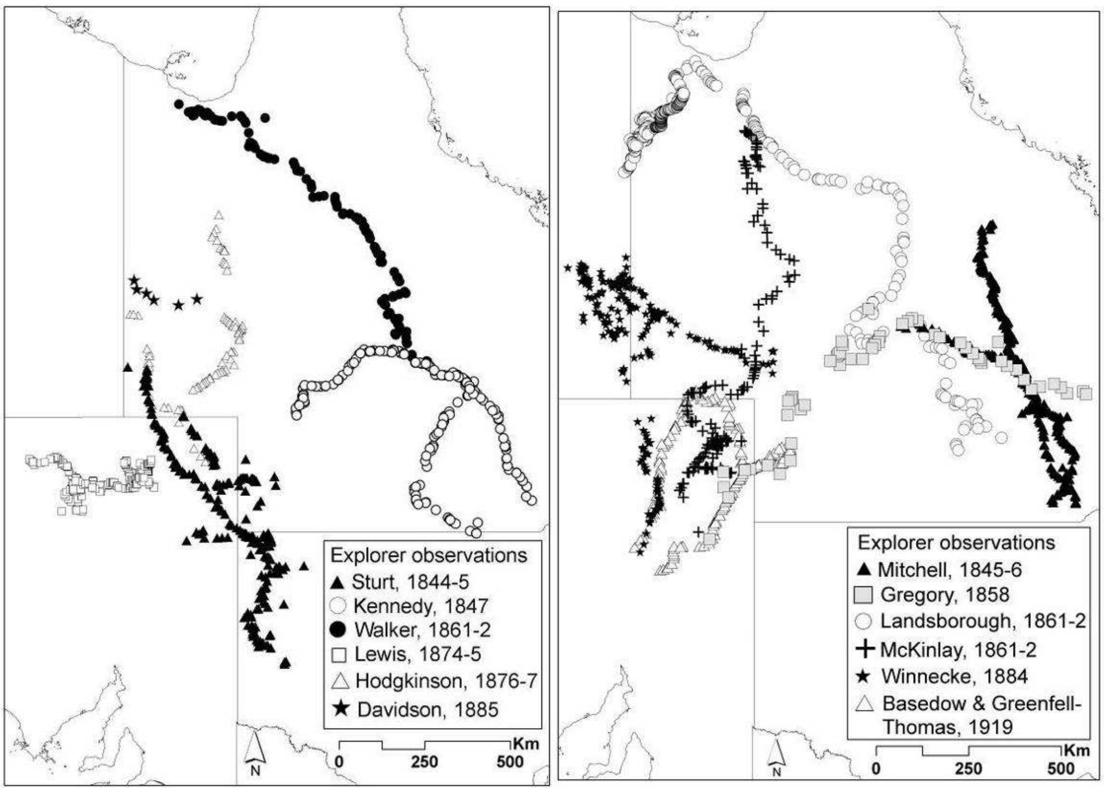


Figure 2-2. Geo-referenced explorer observations from *(a)* Mitchell, Gregory, Landsborough, McKinlay, Winnecke and Basedow & Greenfell-Thomas, *(b)* Sturt, Kennedy, Walker, Lewis, Hodgkinson and Davidson

Vegetation change

The fourteen journals contained between 35 (in Walker) and 330 (Mitchell) descriptions of vegetation structure. Here we concentrate on observations from the semi-arid zone where there is widely assumed to have been a general thickening of woody vegetation since pastoral settlement, especially of mulga (Moore *et al.* 2001; Beale 2004) and gidgee (Reynolds and Carter 1993) (see Appendix 2-1 for further references). We hypothesise that there will be numerous examples where explorers passed through open country that is now thickly wooded. All observations discussed in this section were able to be located to within 10 km accuracy, and most to within 3 km.

The expeditions of Kennedy (in 1847) and Landsborough (in 1862) provide descriptions of vegetation structure in the mulga (*Acacia aneura*) forests of southern Queensland. Both journals reveal that the country was a mosaic of thick mulga forest, grassy woodland, open flats along the rivers and mixed woodland or cypress pine sand ridges (Table 2-4). Heading south along the Warrego River, the country opened into extensive Mitchell grassland, invoking superlatives from the explorers.

Such enthusiasm contrasts sharply with the comments of the explorers in the mulga country to the north. Kennedy had difficulty traversing some sections due to its 'scrubby and sandy' nature. At one point, about 25 km north of present-day Charleville, he found the mulga 'too thick to penetrate' (2 November 1847). Landsborough, with his ever-keen eye for pastoral opportunity, lamented the poor nature of much of the country. While there were some well-grassed and thinly wooded areas, his journal is dominated by descriptions of 'barren scrubby ridges…thickly wooded with mulga' and 'scrub…consisting of mulga with few other trees' (3 May 1862). West of the Warrego, some of the country was 'well covered with kangaroo grass, but in the last part of the journey it was too scrubby to be well grassed' (6 May 1862). South-east of Charleville, 'the country…was so bad that I did not wonder at its not being stocked…Where it is not thickly wooded with thick mulga scrub, which chiefly prevails, it is grassed with *Triodia*…' (12 May 1862).

Table 2-4. Vegetation structure observations, Warrego River, Kennedy and Turner (1847) and Landsborough (1862) expressed as a % of total observations

Vegetation summary	Kennedy and Turner	Landsborough	Total
Scrub or thick forest	28.6	40.7	34.5
Open forest or thinly wooded	25.0	25.9	25.5
River flats and treeless plains or grasslands	50.0*	11.1*	30.9
Mixed sand ridges	3.6	11.1	7.3
Pine [*Callitris*] ridges	7.1	7.4	7.3
Spinifex [*Triodia* grassland]	3.6	3.7	3.6
Total observations	*28*	*27*	*55*

* All references to grasslands south of Wyandra (100 km south of Charleville)

Mitchell, who travelled through a small area of the eastern mulga forests in New South Wales and Queensland, mentions battling through or avoiding dense 'Malga' six times, and regarded it as representing 'to the traveller the most formidable of scrubs' (24 March 1846). These observations refute a prevailing myth, shared by many long-term residents and some researchers, that 'most of the mulga was open savannah at the time of European settlement' (Beale 2004:2). Landsborough's general comment on the nature of the mulga country is informative: 'The country was thinly wooded in some places and scrubby at others' (17 May 1862).

A matrix of open Mitchell grasslands and *Acacia* woodlands, primarily gidgee (*Acacia cambagei* R.T. Baker) and boree (*Acacia tephrina* Pedley) with smaller areas of brigalow (*A. harpophylla* F.Muell. ex Benth.) and myall (*A. pendula* A.Cunn. & G.Don), occurs in central Queensland in the vicinity of Blackall and Longreach. The area was traversed by five explorers – Mitchell, Kennedy, Gregory, Walker and Landsborough – between 1846 and 1862. Together, they made over 100 observations of vegetation structure in this region, which can be classified into four broad structural classes (Table 2-5).

Table 2-5. Vegetation structure observations in central Queensland, expressed as percentage of all observations by each explorer

Vegetation summary	Mitchell (n=28)	Kennedy (n-=32)	Gregory (n=7)	Landsborough (n=24)	Walker (n=13)	TOTAL (n=103)
Scrub or thick forest (gidgee)	28.6	31.3	57.1	16.7	30.8	29.1
Open forest (boree or gidgee)	14.3	9.4	0.0	12.5	7.7	9.7
Thinly wooded downs	3.6	15.6	14.3	58.3	0.0	20.4
Downs/plains	53.6	43.8	28.6	12.5	61.5	40.8

These observations show that the country was a matrix of thick gidgee ‘scrubs’, thinly wooded downs and open plains. The open and thinly wooded downs most impressed the explorers, and led Mitchell to declare it ‘the finest region I had ever seen in Australia’ (22 September 1846). The prior experience of dense scrubs enhanced his appreciation of the downs. East of Tambo, Mitchell found the scene ‘most refreshing…on emerging from so many thick scrubs’ (15 September 1846). In some cases, the scrubs were so thick that the explorers were forced to cut a path for their wagons or avoid them altogether. About 20 km east of Tambo, Kennedy ‘…had to cut thro’ a dense Brigalow Scrub’ (23 July 1847). Similarly, Walker’s progress ‘was checked by a dense, almost impenetrable scrub of acacia [gidgee]’ (1 October 1861). Along the Thomson, Landsborough generally travelled through thinly wooded downs, until approaching the Barcoo north of Yaraka, where the country became ‘so thickly wooded at places with western-wood acacia that riding fast was too dangerous to be agreeable’ (19 April 1862).

The open and wooded downs now support a profitable pastoral industry. The gidgee and brigalow woodlands have been much reduced in extent by broadscale clearing, while the remnant woodlands are widely believed to have ‘thickened up’ since pastoral settlement (Reynolds and Carter 1993). While there has been substantial thickening of gidgee in some areas over the past 50 years (Fensham and Fairfax 2005), the explorer record shows that there were large expanses of dense gidgee in pre-European times.

Rather than providing evidence of unidirectional change, the explorer journals suggest a natural dynamism in woodland/grassland dynamics on century scales (Fensham and Holman 1999). Mitchell, Kennedy and Gregory all recorded vast areas of dead 'brigalow' (actually gidgee) along the Barcoo. About 100 km north-west of Blackall, Mitchell described '…extensive downs, in many parts of which dead brigalow stumps remained, apparently as if the decay of that species of scrub gave place to open downs' (24 September 1846). Later, retracing his steps but on the southern side of the river, he observed that 'an uncommon drought had…killed much of the brigalow scrub so effectually, that the dead trunks alone remained on vast tracts…' (1 October 1846). A year later, Kennedy mused that 'from the appearance of the downs which are strewed with dead timber…it is evident that at some time or another they must have formed one vast scrub' (10 August 1847). Dead timber was a feature of the country for over 100 km: 'From the quantity of dead timber strewed over the ground it would appear that the scrubs are fast decaying and Plains left in their room…' (11 August 1847). Twelve years later, the dead timber remained but was no longer standing, 'rending the country almost impracticable from the quantity of fallen dead timber' (Gregory, 26 May 1858). The probable cause of the dead trees is extreme drought, but the magnitude of this event must have been far greater than that which occurred in the 2000s when the area west of Blackall experienced two of its driest years on record in 2002-2003 as well as below-average rainfall in 2005-2006 (Bureau of Meteorology 2012) without killing extensive areas of trees.

Overall, the explorer record suggests surprisingly little change in vegetation structure across inland eastern Australia, given the huge and abrupt changes in land-use with the commencement of pastoralism. This contrasts with studies from other areas, such as Crowley and Garnett (1998) from Cape York and Lunt (1998) from a coastal woodland remnant in southern Australia, which detected a general thickening of vegetation compared with the explorer record. However, in western New South Wales the only significant changes in vegetation structure were related to broadscale clearing (Denny 1987). Other studies from the Queensland rangelands that have applied a systematic and quantified approach to employing the historical record reveal scant evidence of unidirectional change in woody vegetation structure (Fensham 2008; Fensham *et al.* 2011a).

Fire

There is a general view that fires are less frequent across the semi-arid zone, especially in the mulga forests and Mitchell grasslands, due to lower biomass with livestock grazing and active suppression by pastoralists (Scanlan and Presland 1984; Reynolds and Carter 1993). While some authors argue that fire would never have been a regular occurrence in mulga communities due to sparse biomass in most seasons (Dawson *et al.* 1975; Hodgkinson 2002), other researchers and many land managers invoke a loss of regular fires to explain perceived tree and shrub thickening and expansion (Duyker 1983; Reynolds and Carter 1993; Moore *et al.* 2001). In spinifex-dominated landscapes, current theory suggest that small, regular 'patch burns' have been replaced by large wildfires following periods of high rainfall, with devastating effects for fire-sensitive communities and species (Allan and Southgate 2002; Latz 2007). We hypothesise that burning was regularly noted by explorers in semi-arid areas and spinifex-dominated ecosystems.

The journals analysed encompass a total of 60 months travel spanning seven decades and thus a broad range of seasons and weather. Most references to fire relate to smoke from Aboriginal camp fires or smoke signals, some lit in response to the explorers' presence, with only 25 pertaining to wildfire. Thirteen of these were observed burning, while the remainder had occurred prior to the explorers' arrival and were noted as burnt ground or post-fire regeneration. Twelve observations refer to floodplains and eucalypt woodlands, often along creeklines, in areas receiving >500 mm rainfall on the eastern margin of our study area (Table 2-3). Here, Mitchell noted that Aboriginal people made the most of hot winds 'to burn as much as they could of the old grass, and a prickly weed which, being removed, would admit the growth of a green crop, on which the kangaroos come to feed…' (18 May 1846).

With the exception of grassfires in the Mitchell grass (*Astrebla* species) grasslands in the far east and north of the study area and spinifex (*Triodia* species) deserts, fires were rarely noted by the explorers in areas receiving <500mm rainfall. There are four references to Aboriginal people burning Mitchell grasslands, all on the northern and eastern edge of the semi-arid zone. Mitchell noted a grassfire in central Queensland, writing that 'the extensive burning by the natives, a work of considerable labour, was performed in dry weather' (13 September 1846), suggesting that, even prior to the introduction of domestic livestock, biomass was only sufficient to support large fires during dry windy spells and probably after good seasons (Griffin and Friedel 1985; Hodgkinson 2002). McKinlay recorded 'Blackfellows burning grass…the first bushfire we have seen' at the end of April 1862, when in the northern Mitchell grasslands and nearing the end of his seven-month journey from South Australia, while Landsborough noted recently-burnt grassland along the Flinders River (24 February 1862). Five fire references were from spinifex (*Triodia* species) country, two each from the Simpson Desert dunefields (Winnecke, September-October1884) and sandplains south of Charleville (Turner, 4 November 1847 and Kennedy, 20 November 1847), while McKinlay observed Aboriginal burning in the *Eucalyptus* and spinifex-dominated Selwyn Ranges south of Mt Isa in May 1862.

These observations, including no references to fire in over 600 km travelled through mulga forest, including during early summer when spinifex in the same area was being burnt, and just two references in 2790 km of Mitchell grasslands traversed (Table 2-3), suggest that fire was rare throughout most of the semi-arid zone. This lack of fire in inland eastern Australia contrasts with regular dry-season burning in higher rainfall areas across northern Australia (Braithwaite 1991; Fensham 1997; Crowley and Garnett 2000; Vigilante 2001; Preece 2002), in the forests of south-eastern Australia (Gott 2005), and spinifex deserts of central Australia (Kimber 1983). It is possible that wildfires following wet years in the Simpson Desert dunefields west of the Mulligan River burn larger areas in the absence of the Aboriginal patch burning noted by Winnecke (Greenville *et al.* 2009). However, the hypothesis of frequent Aboriginal burning across semi-arid Queensland is not supported by the explorer record.

Waterhole permanence

Although Australia's inland river systems are inherently dynamic (Knighton and Nanson 1994; McMahon *et al.* 2008), loss of groundcover through overgrazing is considered to be a primary cause of 'silting' of channels and waterholes in some areas (Kowald and Johnson 1992; Robertson and Rowling 2000; Bell and Iwanicki 2002; Nolan 2003). Many long-term residents in the study area consider that waterholes along some reaches were deeper and more permanent in the past (Silcock 2009). The explorer journals provide the first written records of inland waterholes, prior to the incursion of domestic and feral animals. We hypothesise that explorers recorded long-lasting waterholes in reaches which are now devoid of such features.

Most references to water are not sufficiently detailed to infer the likely permanence of waterholes. Others were made in good seasons or while the river was still flowing, precluding inferences of permanence. For example, the first explorers to describe the Diamantina River, McKinlay (in 1863) and Hodgkinson (in 1877), travelled when the river was in flood, so were unable to provide any reliable estimates of waterhole permanence. Taking these factors into account, there were 101 points where explorer records could be overlaid with current information on permanence (Silcock 2009), spread across 30 reaches of creeks or rivers. The explorer record does not point to substantial changes in depth and permanence for the majority of these. Most deep, permanent waterholes recorded by the explorers remain permanent, while in areas today characterised by a paucity of good waterholes, the explorers struggled to find water. There are, however, a few instances where the status of present-day waterholes differs from the assessment of explorers. While there are two waterholes where permanence has undoubtedly increased, due to excavation or inflow of bore water, the explorer record suggests a decrease in depth and permanence in five cases (Appendix 2-4), three of which are discussed below.

Landsborough's observation of deep waterholes on Silverfox (Four Mile) Creek, a tributary of the Thomson south-west of Longreach suggests change as there are no such holes in these shallow channels today. This inference of silting is corroborated by long-term residents, who remember semi-permanent holes in the area that have now silted up. Long-term residents also believe that silting has affected waterholes in the upper Thomson catchment, including along Towerhill Creek. When Landsborough encountered the creek in its upper reaches, he wrote that ‘All along the creek there are many fine deep waterholes’ (24 March 1862). Anecdotal evidence suggests that these waterholes used to be 6-8 feet deep, but have gradually silted up and some are lucky to last four months (Silcock 2009). However, the ‘fine waterholes’ to the south recorded by Landsborough the following day are still regarded as permanent. The explorer record provides tentative support for anecdotal observations of silting in these creeks, and illustrates the value of using multiple lines of evidence in historical ecology (Davies and Watson 2007; Goforth and Minnich 2007).

However, anecdotal evidence is not always corroborated by the explorer record. Waterholes along Strzelecki Creek are believed to have silted up due to overgrazing during the droughts of the late 1800s (Tolcher 1986) and as early as 1919 Basedow noted that ‘…drift sand has ruined many once good waterholes’ (25/8/1919). Sturt’s journal is particularly valuable along Strzelecki Creek because he travelled during a very dry time in the mid-1840s and re-visited the waterholes three times. His journal provides little support for a decline in waterhole permanence during the early phase of pastoralism. His journal entries of August 1845 paint a picture of the channel as being ‘of considerable width, tho not depth’ (18 August 1845) and containing several broad waterholes. These waterholes still contained ‘considerable water’ in October 1845, but when the party returned a month later, they ‘found nothing but mud in the one and the water in the other very little better than mud’ (10 November 1845). This third visit indicates that these waterholes were certainly not permanent in Sturt’s time, and are unlikely to have ever been anything but broad, shallow holes. Gregory, who traversed 120 km of Strzelecki Creek, corroborates this, writing that ‘No permanent water was seen along the bed of the creek although there are many deep hollows which, when once filled, retain water for several months’ (21-25 June 1858).

Detecting the silting of waterholes through the explorer record is stymied by intermittent visitation by explorers, incorrect interpretations of permanence and the inherent natural variability in the system. While recognising these limitations, there are many stream reaches where the record has sufficient resolution to detect change and our results suggest that the depth and thus permanence of waterholes has not changed greatly across most of the study area. The overall interpretation that waterholes are relatively constant despite environmental upheavals, including climate change associated with glacial cycles, is supported by geomorphological studies (Nanson *et al.* 2008; Magee *et al.* 2009).

Macropod numbers

It is widely believed that larger macropods (the red kangaroo, *Macropus rufus*, eastern grey, *M. giganteus*, western grey, *M. fuliginosus* and wallaroo, *M. robustus*) have increased in number and range in semi-arid areas since pastoral settlement, due to the provision of artificial sources of water, dingo control and vegetation changes associated with livestock grazing (Newsome 1975; Calaby and Grigg 1989; Fukada *et al.* 2009). In particular, *M. giganteus* has expanded into more arid areas in the past 30-40 years (Dawson *et al.* 2006). Average densities of *M. rufus*, *M. giganteus* and *M. robustus* in semi-arid Queensland are now 8.5/km^2, 8.5/km^2 and 4.9/km^2, respectively (Department of Environment and Resource Management 2011). However, the explorer record has been employed to challenge this conventional view by showing the kangaroos have always been abundant in many areas of southern and eastern Australia (Denny 1980; Auty 2004). Red kangaroo numbers seem to have always been patchy and fluctuated with seasons in more arid areas (Calaby and Grigg 1989). We hypothesise that few macropods were recorded by explorers in the semi-arid zone but they saw relatively large numbers in areas above 500 mm rainfall, while numbers recorded in the arid zone were variable but generally low.

Interpreting kangaroo density from the explorer record is fraught, because the absence of records does not confirm an absence of animals. In fact, kangaroos may have been so commonplace that they did not rate a mention. However, the journals cited by Denny (1980) and Auty (2004) show that most explorers, including Mitchell in his earlier expedition along the Murray River, tended to note if kangaroos were abundant. In addition, in areas where they were common, kangaroos were an important game item for exploring parties, and thus worthy of a mention in the journals. For example, north of the Diamantina, McKinlay was pleased that ‘Hodgkinson shot a euro which will help us on’ (15 April 1862), while nearly all explorers devoted considerable time to the pursuit of game to supplement their meagre supplies.

The fourteen explorer journals examined here together contain 33 references to macropod sightings (Table 2-3). Almost half of these are by Basedow and Greenfell Thomas, indicating that in 1919, red kangaroos were a common sight in the arid-zone (<250 mm mean annual rainfall) of north-eastern South Australia and far south-west Queensland. Also writing about the arid-zone, Davidson is explicit in defining kangaroo densities, noting ‘a family of three kangaroos, the only ones seen west of Boulia’ (1885). McKinlay records that kangaroos were common in three locations, all towards the end of his journey, suggesting that he had been seeing only small numbers throughout the rest of his journey along the Diamantina. Just before leaving the Diamantina catchment, McKinlay thought the sighting of a single wallaroo noteworthy enough to name a hill ‘Euro Hill’ (6/4/1862). Sturt’s journals contain three references to kangaroos in far north-western New South Wales and north-eastern South Australia, suggesting that they were not abundant in this area.

Mitchell’s journals suggest that kangaroos were abundant in areas of central-southern Queensland, outside the semi-arid zone (>500 mm mean annual rainfall). The plains east of Tambo were ‘heavily imprinted with the feet of kangaroos’ (13 September 1846). However, in the semi-arid region (250-500mm), the journals of Mitchell, Kennedy and Gregory contain only one mention of kangaroos along the Barcoo from Tambo to Yaraka (two large red kangaroos noted by Kennedy on 5 August 1847) – an area where eastern grey kangaroos, red kangaroos and wallaroos are now in relatively high densities (Department of Environment and Resource Management 2011). Furthermore, Turner writes on an almost daily basis of his attempts to procure meat for Kennedy’s party along the Barcoo, including emus, a variety of birds and even in one case dingo pups, but does not once report seeing a macropod.

Kennedy’s observation north-east of Charleville is revealing: ‘Two Kangaroos were shot today. They are the first we have observed on the journey’ (2 July 1847). Although Mitchell recorded kangaroos twice in this area the previous year, Kennedy’s comment suggests that they were rarely sighted. Landsborough noted that kangaroos were numerous north of Camooweal, on the edge of the semi-arid zone (30 November 1861 and 6 January 1862). However, he only mentions them once on his journey from there to the Warrego, a total distance of almost 2000 km, passing through areas where kangaroos are now extremely abundant. North-west of Charleville, he wrote: ‘In this day's journey we saw more kangaroo and wallaby than on any previous occasion…' (6 May 1862). This implies that the party had been seeing small numbers of kangaroo throughout the journey, but the individual sightings are not recorded in Landsborough's journals.

Overall, analysis of the record supports the hypothesis that kangaroos were rarely recorded in the semi-arid zone, were patchy in areas with less than 250 mm mean annual rainfall, probably with population booms during times of above-average rainfall (Calaby and Grigg 1989), and abundant in some areas with >500 mm annual rainfall. The paucity of kangaroo observations in the explorer record across most of the semi-arid zone suggests that eastern grey kangaroos and wallaroos are found in much higher densities today than they were prior to pastoral settlement.

Medium-sized mammals

The extinction and range contraction of medium-sized mammals across inland Australia is well documented (Letnic 2000; Johnson 2006). We hypothesise that medium-sized mammal species were recorded by explorers in areas where they no longer occur. The journals provide some of the only written field records of small and medium-sized mammals prior to the wave of catastrophic extinctions that swept across inland Australia (Johnson 2006). Two of the most interesting, and previously uncited, references to fauna are from Hodgkinson's journal along the Mulligan River in far western Queensland in 1876. North-west of Birdsville, he observed that 'The kangaroo-rats here build nests three feet high against the trunks of giddia or other trees' (7 August 1876). Based on the description of the nests, this observation probably refers to the now-extinct *Caloprymnus campestris*, and is a significant extension of its known former range (Finlayson 1932; Strahan 2004). Heading north-west into the Toomba Range west of Boulia, Hodgkinson noted 'numerous rock wallabies' in a 'picturesque sandstone gorge' (21 August 1876). This sighting is outside the known historical range of the three inland species of rock wallaby (Clancy and Close 1997), but is most likely to be the purple-necked rock wallaby, *Petrogale purpuricollis* (Peter McRae, pers. comm., October 2010).

Sturt's party also saw groups of three (4 November 1844) and five or six (15 December 1845) yellow-footed rock wallabies (*Petrogale xanthopus*), in the Barrier Ranges north of Broken Hill. Given that rock wallabies can be cryptic (Gordon *et al.* 1978), for Sturt and his party to see two colonies while passing through the ranges suggests that they were reasonably abundant. They are now considered Vulnerable in New South Wales, the remaining two colonies of 200-250 individuals being restricted to two cliff systems and two outcrops north-east of Broken Hill (Lim and Giles 1987). Sturt recorded numerous other species now rare or extinct in western New South Wales and southern Queensland, including stick-nest rats (*Leporillus conditor*) and greater bilbies ('jalparoos' or 'talperos', *Macrotis lagotis*) (Denny 1994). In 1885 Davidson saw a bilby near Boulia, just outside of their current much-reduced range, and writes that 'They must have been fairly plentiful in these days, as it was customary for the blacks, when in full costume, to wear a sort of garter below the knee from which depended the tails of the bilbie'. The hypothesis that medium-sized mammals are present in the explorer record in areas where they no longer occur is supported.

Enhancing interpretation

The explorer record holds maximum power when it is precisely geo-referenced to allow direct comparison with current circumstances. The combination of easily available Geographic Information System software and free, high-resolution Google Earth imagery has made reconstructing explorer routes much easier, through allowing distances and bearings to be traced on-screen and geographic features mentioned in journals to be readily identified. Precise geo-referencing is not always possible, due to ambiguities and errors in distance and bearing measurements given in journals. In addition, numerous passages refer to observations made over sections of the journey, sometimes encompassing entire days, rather than specific points. Limitations can be acknowledged by attributing spatial precision estimates to observations.

Building a composite picture of numerous explorer records across a region is more powerful than using a single journal in isolation. For example, the low numbers of kangaroos in the Barcoo River area is corroborated by four explorers, while the existence of thick mulga vegetation is verified by three explorers. The explorer record is especially useful when it includes quantification of a given parameter, such as the depth measurements of waterholes provided by Lewis west and north of Lake Eyre. Quotes such as Kennedy's 'this is the first kangaroo seen' are extremely valuable, but frustratingly rare. Similarly, Mitchell and Kennedy's descriptions of having to cut paths through or being unable to penetrate brigalow and mulga scrubs allow us to gauge more specifically what they meant by the term 'thick'. In general, however, the lack of quantification of vegetation structure and waterhole depth, and difficulties associated with inferring absence of animals (Denny 1994) and fire (Fensham 1997), represent major limitations of the explorer record. In contrast, the mere presence of some phenomena is of inherent significance, and the unquantified records of extinct mammals represent an unequivocal example of landscape change.

Selectively plucking quotes from the journals can result in them being taken out of context. Perhaps the most well-known example of this is Mitchell's musings that 'Fire, grass, kangaroos, and human inhabitants, seem all dependent on each other for existence in Australia; for any one of these being wanting, the others could no longer continue'. This oft-quoted passage has been used to imply that most of Australia was regularly burnt and, indeed, dependent upon burning (Flannery 1994; Welsh 2004; Gammage 2011). This is not supported by Mitchell's 1844-5 journal, which contains only occasional references to fire in the 2000 km he travelled through Queensland, and no references in 500 km of the semi-arid zone traversed. Similarly, conclusions regarding the open nature of vegetation in central New South Wales based on selective use of historical sources have been refuted by Benson and Redpath (1997).

CONCLUSION

The explorer record provides rare and graphic insight into the extent of landscape change in a region. When examined systematically by geo-referencing all available sources as accurately as possible, testing specific hypotheses and using contemporary observation and understanding of landscape to empower historical interpretation, it can inform key aspects of contemporary land management debates. The explorer record for our study area suggests little change in broad vegetation structure or waterhole permanence. Fires were infrequent and mostly restricted to higher-rainfall grasslands and spinifex-dominated ecosystems. The historical ranges of some medium-sized mammals that are now extinct or rare have been expanded. The dominant large herbivores (macropods) were relatively uncommon in semi-arid areas where they are abundant today. These conclusions are not always consistent with existing dogma but should contribute to debates underpinning contemporary rangeland management and conservation, including land clearing guidelines and legislation, fire management and harvesting of native species. This paper provides a blueprint for rigorous interrogation of this valuable and unique record which can be used to test prevailing assumptions common to arid systems that have been subject to abrupt management upheaval.

CHAPTER 3.

ARID VEGETATION IN DISEQUILIBRIUM WITH LIVESTOCK GRAZING: EVIDENCE FROM LONG-TERM EXCLOSURES

INTRODUCTION

The past three decades have seen debate surrounding the validity and utility of two paradigms for interpreting rangeland vegetation dynamics. The ‘equilibrium paradigm’ considers grazing systems to be internally regulating, with relatively constant abiotic patterns and tight coupling between plants and herbivores, wherein herbivore densities are sufficient to consume available plant biomass (Briske *et al*. 2003). This view has been challenged for highly variable rangeland systems, where external climatic events are critical to system dynamics and tend to override internal biotic controls (Ellis and Swift 1988). Such grazing systems are purported to display non-equilibrium dynamics, including weak coupling between the responses of plants and herbivores (Westoby *et al.* 1989; Jackson and Bartoleme 2002; Retzer 2006). Some authors have argued that the risk of environmental degradation through overgrazing in non-equilibrium systems is limited, because the ephemeral forage is only in abundance for brief, sporadic periods amidst frequent protracted drought, keeping livestock numbers well below equilibrium, either through animals starving in the field or being moved to other areas (Ellis and Swift 1988; Ward *et al.* 1998; Sullivan and Rohde 2002).

Despite the apparently opposing features of these paradigms, recent reviews argue that they are not mutually exclusive (Walker and Wilson 2002; Briske *et al.* 2003; Vetter 2005). Ecosystems can exhibit both equilibrium and non-equilibrium dynamics at a variety of spatial and temporal scales (Connell and Sousa 1983; Fernandez-Gimenez and Allen-Diaz 1999). For example, the uneven distribution of grazing pressure means that certain ‘key resource areas’ can be in equilibrium and hence more vulnerable to degradation, while the majority of the landscape is not in equilibrium (Illius and O'Connor 1999). The period over which vegetation is recorded, and the prevailing seasonal conditions, can also lead to differing interpretations of vegetation dynamics (Fuhlendorf *et al.* 2001). The challenge is then to understand where and under what circumstances different dynamics apply, as this will have fundamental consequences for management. Interventions based on the equilibrium paradigm will tend to focus on reducing stocking rates in an attempt to increase stability and halt declines in the palatable and sensitive components of the vegetation. Proponents of the non-equilibrium paradigm argue that arid ecosystems are resilient to opportunistic stocking strategies, where stock numbers are increased during periods of abundant growth following unpredictable rainfall but are unable to be sustained through protracted droughts. The assertion that non-equilibrium rangelands are not vulnerable to degradation, and that management interventions aimed at reducing stocking rates are unnecessary, has generated considerable controversy (Watson *et al.* 1996; Sullivan and Rohde 2002; Vetter 2005). At its extreme, this view implies that given the vagaries of the climate, management is of little consequence in arid rangelands (Illius and O'Connor 1999).

Historical and ecological accounts have entrenched the perception of degradation across much of arid Australia (Tolcher 1986; White 1997; Letnic 2000). Impacts documented in other parts of central Australia include a loss of ground cover, mostly long-lived perennials and grasses, accelerated erosion and changes in species composition due to decline of selectively-grazed species (Leigh *et al.* 1989; Friedel 1997; Landsberg *et al.* 2002; Tongway *et al.* 2003; Read 2004; Johnson *et al.* 2005). However, there is a general perception in the grazing community that impacts on the vegetation in flooplains and surrounding landscape of inland Queensland are slight (Edmonston 2001), and a recent study showed little evidence of irreversible degradation in the Simpson Desert dunefields after 20 years of grazing by cattle (Fensham *et al.* 2010a). These authors found almost no patterns in plant cover, species richness or abundance of life forms in relation to grazing, and argued that the ephemeral life history response of the majority of species to unreliable rainfall effectively doubled as an adaptation to surviving grazing. Unfortunately, there is little quantified evidence from which to assess the validity of these divergent perceptions of degradation for the vast dunefields and plains that characterise north-eastern South Australia and south-western Queensland.

Grazing exclosures provide an opportunity to gather empirical evidence to distinguish between equilibrium and non-equilibrium vegetation dynamics (O'Connor and Roux 1995; Ryerson and Parmenter 2001). If there are significant differences in species abundance and composition between grazed and ungrazed treatments, there are negative feedbacks between grazing intensity and vegetation dynamics. It follows that the system is approaching an equilibrium state, and may therefore be vulnerable to long-term degradation through overstocking (Vetter 2005). If no differences are detected between treatments after a reasonable period of grazing exclusion, two alternative interpretations are possible. One scenario views the system as being resilient to grazing and therefore not degraded. This interpretation is consistent with the view that non-equilibrium dynamics will predominate in highly variable arid rangelands, where drought is the major stress on the system and animals rarely reach equilibrium with their fluctuating resource base (Fernandez-Gimenez and Allen-Diaz 1999). Alternatively, the system may have already lost grazing-sensitive species prior to the exclosures being erected, thereby precluding recovery with removal of grazing. Under this interpretation, grazing has resulted in a persistent and resilient vegetation assemblage dominated by grazing-tolerant species, usually short-lived species that can complete their life cycles rapidly (Milchunas *et al.* 1988; Leigh *et al.* 1989; Landsberg *et al.* 2002; Oba *et al.* 2000). This view is also consistent with the non-equilibrium paradigm, which accommodates discontinuous and non-reversible changes to vegetation communities (Briske *et al.* 2003).

This study explores these three alternatives using five 14-year exclosures in dunefield and floodplain land systems on Innamincka Regional Reserve. Species composition and abundance are compared between cattle exclusion areas and adjacent cattle-grazed plots. We discuss the possible interpretations of our results in the context of equilibrium and non-equilibrium paradigms for interpreting rangeland vegetation dynamics, and in relation to regional and property stocking rates and a regional analysis of the flora to detect species that may have declined under grazing. Implications for management of these rangelands and future research directions are discussed.

METHODS

Five exclosures on Innamincka Regional Reserve in the north-eastern corner of South Australia (Figure 3-1) were measured in May 2010. These exclosures were established in 1996 by the National Parks and Wildlife Service of South Australian and S. Kidman & Co. Ltd. Average annual rainfall for Innamincka is 174 mm. Since the sites were established, rainfall has averaged 172 mm per annum. However, the defining feature of rainfall is its extreme variability, with a coefficient of inter-annual variation of 67% and long periods of aridity punctuated by occasional heavy rains. Site measurements were preceded by an exceptionally wet summer, with 380 mm falling from November 2009 to April 2010 inclusive, compared to the long-term average for this period of 114 mm. Innamincka received 186 mm in February 2010, making it the wettest February since records began in 1883.

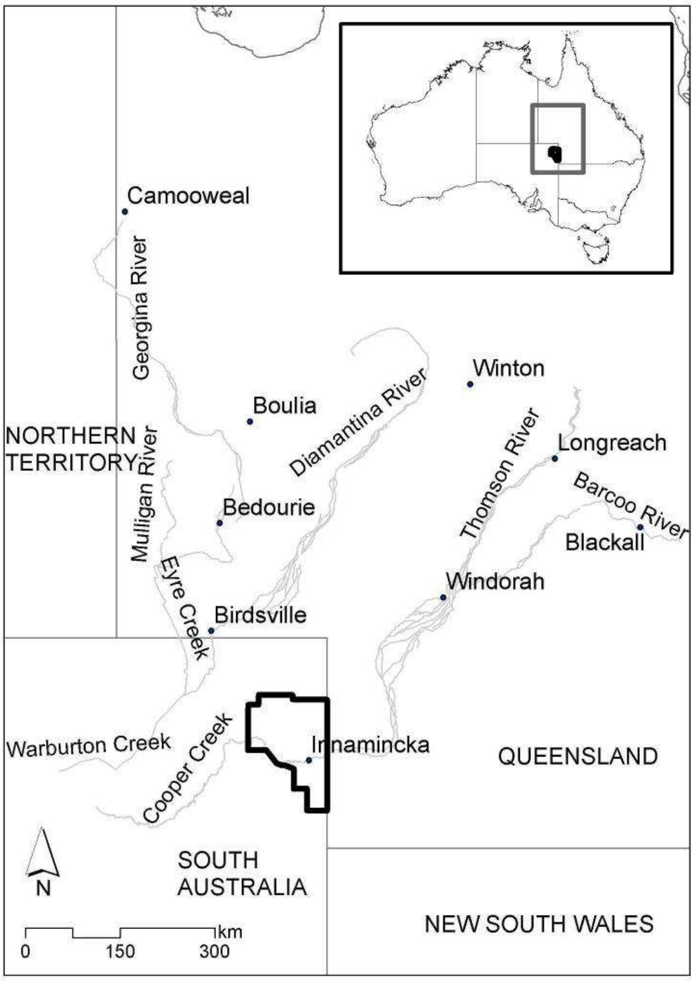


Figure 3-1. Location of Innamincka Regional Reserve, showing state borders, major towns and watercourses

At each site, a 50 m x 50 m four-strand barbwire fence excluded cattle. An equivalent plot was established outside each fence as the cattle-grazed treatment (Figure 3-2). Cattle grazing has occurred across all sites for 130 years (Tolcher 1986), with recent densities between 0.007 and 0.030 beast per hectare, although this fluctuates with rainfall (Table 3-1). These stocking rates are similar to surrounding properties with similar land types, and may be slightly higher in the vicinity of the exclosures due to the proximity of waterholes and floodouts of the Cooper and Strzelecki systems (John Maconochie, pers.comm., October 2011). All sites have had periods of complete de-stocking within the last ten years. Red kangaroos would not be excluded from the exclosures, but are in low densities and do not represent a significant contribution to total grazing pressure (G. Campbell, pers. comm., 2010).

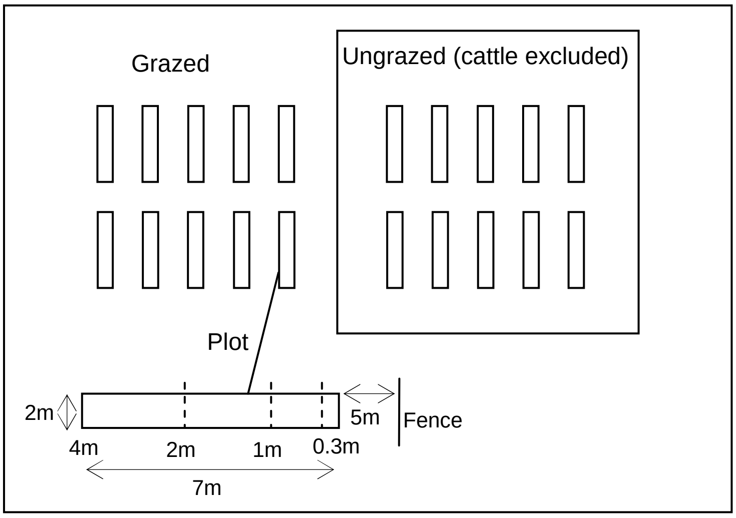


Figure 3-2. Layout of 50 m × 50 m exclosures and sampling design. Floristic data was collected in 7 m × 2 m plots, with abundance score 1-4 in the subplots (bottom left-hand corner, increasing in size from right to left)

Site 1 (27.3817° S, 140.6717° E) is on the toe-slope of a low dune, site 2 (27.7303° S, 140.5956° E) is on a floodplain with cracking clay soil and a low open Eucalyptus coolabah woodland, site 3 (27.9586° S, 140.7756° E) is on a slight stony rise amongst low dunefields, site 4 (28.0206° S, 140.6969° E) is in a sandy-loam dune swale and site 5 (27.8375° S, 140.6589° E) is on a sandplain with scattered low shrubs of *Hakea eyreana* and *H. leucoptera* (Figure 3-3). No trees or shrubs were present at sites 1, 3 and 4.

Table 3-1. Stock numbers, paddock areas and average stocking rate for paddocks containing exclosures, Innamincka Station. Maximum stocking rate is defined as the highest stocking rate at any time in past 10 years. Data supplied from S. Kidman & Co. records.

Site (Paddock)	Stock Number in May 2010	Average stock number	Maximum number of stock	Paddock area (ha)	Average stocking rate/ha
1 (Barton's)	267	150	550	20 200	0.007
2 (Goonaburroo)	1250	750	2859	100 400	0.007
3 (Bore track north)	639	1250	2800	126 100	0.010
4 (Bore track north)	639	1250	2800	126 100	0.010
5 (Mandy's)	0	40	101	1 370	0.030

Figure 3-3. Innamincka sites 1-5, clockwise from top left. Note that Site 5 uses a paddock fence rather than exclosure, as cattle do not graze the northern (left) side due to absence of water; plots were situated 6 m from fence to avoid track

Sampling was undertaken in ten plots in the ungrazed and grazed treatments at each site (Figure 3-2). The dataset therefore comprised 100 plots (5 sites × 2 treatments × 10 sub-samples). Plots were aligned with every second picket along the fences, with five plots situated along lines 5 m from the fence on both sides of each treatment. Each 2 x 7m linear plot was split into four sub-plots of increasing size. Plant species present in the first 0.3 × 2 m sub-plot were assigned an abundance score of 4, new species present in the next 0.7 × 2 m sub-plot an abundance of 3, new species in the next 2 × 2 m sub-plot an abundance of 2, and the final 2 × 4m sub-plot an abundance of 1 (Figure 3-2). This method, involving unrepeated scoring of species presence, has been demonstrated to provide the best return (robust measure of species density) for effort (no more time than presence-absence scores), thereby allowing for a relatively large quadrat size (Morrison *et al.* 1995). Voucher specimens of have been lodged at the Queensland Herbarium. Nomenclature follows Bostock and Holland (2007).

Herbaceous biomass was collected from a bulked sample of ten, 30 x 30 cm frames positioned between the floristic plots. Ten soil samples were collected and bulked for each treatment. Particle size distributions were determined using laser diffraction (Mastersizer 2000, Malvern Instruments Ltd), which is a cost-effective and reproducible technique (Arriaga *et al.* 2006), although relative to the traditional hydrometer and pipette methods there is tendency to underestimate clay and overestimate silt particles (Pieri *et al.* 2006; Eshel and Levy 2007). The soil sample was sieved (2 mm) and dispersed in a solution of 5.5 g/L sodium hexametaphosphate for 24 hours. Just prior to measurement, samples were sonicated for one minute at 10 μm tip displacement to break up remaining aggregated particles. Absorption was maintained between 15-20% during particle size measurement. The output of continuous particle size distribution was segmented as clay (particles <0.002 mm), silt (0.002-0.02 mm), fine sand (0.02-0.2 mm) and coarse sand (0.2-2 mm).

The data were ordinated using non-metric multidimensional scaling using the default settings in DECODA (Minchin 1991). Exploratory analysis revealed site 2 as an extreme outlier and for presentation this site was excluded in a final two-dimensional solution with a stress factor of 0.16. Significant differences in plant composition were compared between treatments at individual sites using the ANOSIM procedure within the PRIMER software. Species contributing to these differences were identified using the SIMPER procedure.

Statistical models were developed to assess the effects of grazing treatment on total species richness and the abundance and species richness of the various life form groups (annual herbs, perennial herbs, annual grasses and perennial grasses). Woody species were present only at site 2 (an open *Eucalyptus coolabah* woodland) and in one plot at site 5 (*Hakea leucoptera*), and were not considered in the analysis. The abundance response was taken as the cumulative abundance scores for each group at each plot. Most of the response variables were either approximately normally distributed or could be normalised via square-root transformation, permitting the use of linear models. Given the nested spatial structure of the sampling design (Fig. 3-2), mixed-effects models were adopted for all responses. We included the following random effects (grouping variables) in all models: (1) site, (2) fenceline within site and (3) plot within fenceline within site. Thus, at the lowest level of each model there were ten plots arranged linearly. While mixed-effects models are effective at partitioning variance between grouping variables in such nested situations, it is important to assess the independence residuals at the lowest level (plot in this case) during statistical inference. To do this, models were fitted with treatment as a fixed effect along with the above-mentioned random effects. Empirical autocorrelation functions (Box *et al.* 1994) of within-plot residuals were then plotted to investigate spatial dependence. For most responses, there was no difference between these models. The nlme R package (Pineiro and Bates 2004) was used to fit all linear mixed-effects models (LMMs). Once an adequate model structure was developed for a given response, the fixed effect (treatment) was assessed using F-tests, and the mean and confidence intervals for each species group by treatment were calculated.

The history of botanical collections in the area dates from the 1880s, less than ten years after the first cattle stations were taken up along the Strzelecki Track (Tolcher 1986), and has continued steadily to the present day. Due to an absence of ungrazed reference sites to inform pre-settlement composition of the dunefields and floodplains of north-eastern South Australia, a systematic search was conducted to identify plant species that may have exhibited declines as a result of grazing. A list of all species known to occur in these two habitats in north-eastern South Australia (defined as that area east of the Diamantina/Warburton and north of the Queensland-New South Wales border, Fig. 3-1) was compiled from South Australian herbarium records, available online through the Electronic Flora of South Australia (www.flora.sa.gov.au). The distribution and abundance of 420 native species (235 of which occurred in dunefields and 252 on floodplains; numerous species have been recorded from both habitats) were assessed as potentially threatened using the criteria: (a) identified as highly palatable or showing a declining trend in the published literature (b) known from <20 populations across its range, or (c) fewer than three collections in the study area in the past 20 years. These ‘candidate species’ were then subject to further scrutiny using specimen notes, online herbaria, and expert and personal knowledge, and classified as either (a) known from more than 20 populations in dunefields, floodplains or other habitats subject to commercial rangeland pastoralism, with a total population size of >100 000 and with no evidence of decline or lack of regeneration, or (b) not (a), and therefore rare and potentially threatened or declining under grazing (Fensham *et al.* 2011b).

RESULTS

Soils at all sites were dominated by fine sand particles. Situated on a floodplain, site 2 had the highest clay and silt content and the lowest coarse sand content. Site 1 was characterised by higher clay content than the other three dune sites (Table 3-2). All sand dune sites except site 1 were slightly more acidic than site 2. Herbaceous biomass was very low across all sites and treatments, and was higher in ungrazed treatments at only two out of the five sites (Table 3-3). The high biomass figure for the ungrazed treatment at site 1 was skewed by one very high-yielding quadrat, and this difference was not obvious across the site.

Table 3-2. Mean soil values and standard errors for sites (replicates represented by the two treatments)

	1	2	3	4	5
Clay	9.56(0.55)	13.47(0.50)	6.72(0.52)	5.49(0.38)	6.93(0.38)
Silt	26.27(2.15)	36.30(2.31)	26.51(1.37)	21.12(2.29)	24.73(1.08)
Fine sand	39.67(2.14)	42.94(2.55)	55.86(0.68)	56.05(0.77)	45.84(1.04)
Coarse sand	24.50(4.83)	7.30(0.27)	10.92(1.21)	17.35(1.90)	22.50(2.50)
pH	7.36(0.08)	7.33(0.15)	6.88(0.02)	6.87(0.07)	6.98(0.02)

Table 3-3. Mean herbaceous biomass ($t.ha^{-1}$) by site and treatment, determined from ten bulked 0.0025 m^2 samples.

Site	Ungrazed	Grazed
1	1.41	0.39
2	0.85	0.35
3	0.26	0.39
4	0.37	0.75
5	0.52	0.93

An ordination diagram prepared after deleting Site 2 revealed differences between sites but no consistent trend in floristic dissimilarity between the grazed and ungrazed treatments (Figure 3-4). All dunefields sites were dominated by annual grasses, especially *Enneapogon avenaceus, Enneapogon polyphyllus, Dactyloctenium radulans* and *Tripogon loliiformis*, which were abundant in nearly all quadrats across the four sites (Appendix 3-1). *Aristida contorta* was abundant at sites 1, 4 and 5. Annual herbs were richer and more abundant than perennial herbs at all dunefields sites except site 3, where perennial chenopods such as *Sclerolaena lanicuspis*, *Sclerolaena parallelicuspis* and *Maireana coronata* were common. Site 1 had the highest species richness of all sites, primarily comprised of annual herbs. Annual herbs were dominant at site 2 (Appendix 3-1), comprised of typical floodplain species such as *Bulbine semibarbata, Calotis hispidula, Nicotiana velutina* and *Trigonella suavassissima.*

There were significant differences in individual species composition between the ungrazed and grazed treatments at site 1 (P=0.001) and site 4 (P=0.048), but no significant differences between treatments at the other sites (P>0.05). Species providing the greatest contribution to the differences between treatments at sites 1 and 4 are identified in Table 3-4. Only one species, *Portulaca oleracea*, showed a difference at more than one site and it did not display a consistent trend with grazing.

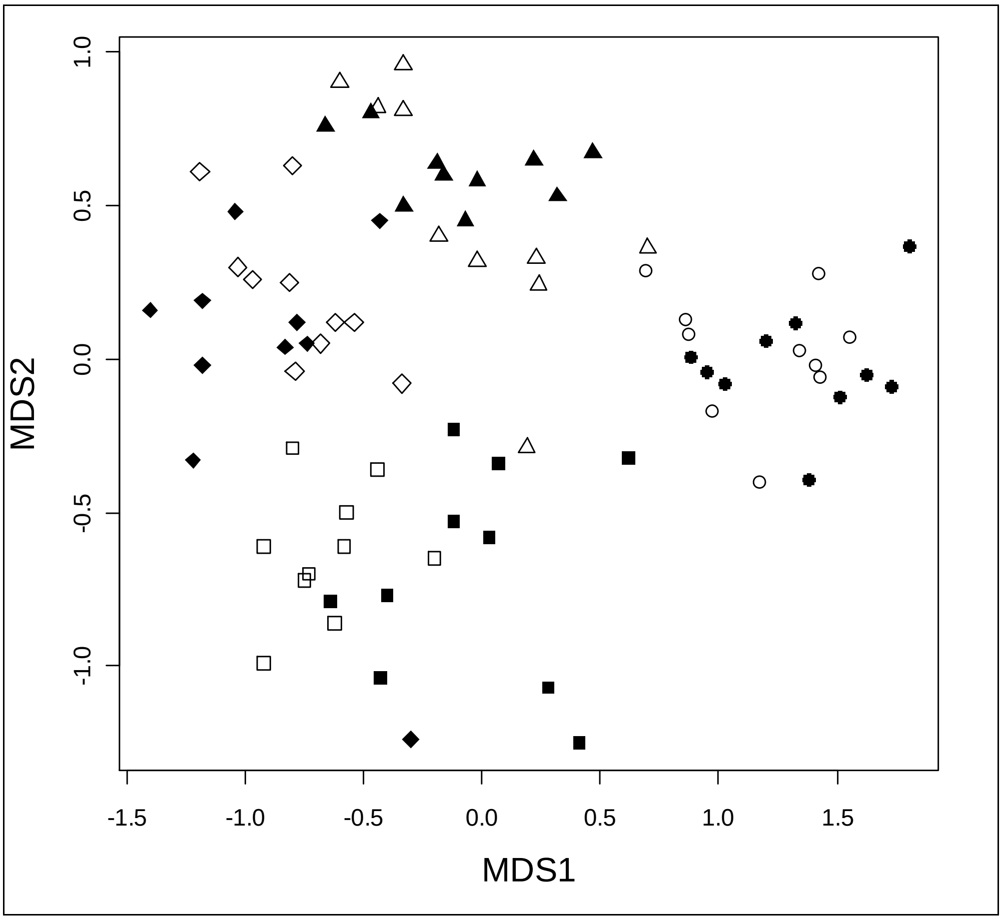


Figure 3-4. Two-dimensional ordination diagram of plots excluding site 2. Site 1 (squares), Site 3 (circles), Site 4 (triangles), Site 5 (diamonds), grazed (open), ungrazed (filled)

Table 3-4. Frequency and average abundance (in brackets) for five species providing the greatest contribution to differences between grazing treatments at sites with significant differences (site 1 and site 4). Note *Portulaca oleracea* contributed at both sites.

Species	Life form	Site 1		Site 2		Site 3		Site 4		Site 5	
		G	UG	G	UG	G	UG	G	UG	G	UG
Aristida contorta	AG	10 (2.3)	8 (1.6)	-	-	-	2 (0.3)	**8 (2.7)**	**7 (2.8)**	9 (3.3)	9 (3.3)
Dactyloctenium radulans	AG	10 (3.4)	10 (4.0)	7 (1.4)	3 (1.0)	9 (3.3)	9 (3.4)	**7 (2.6)**	**9 (2.2)**	7 (2.2)	8 (2.1)
Eragrostis dielsii	AG	10 (2.8)	7 (1.5)	4 (1.2)	4 (1.2)	-	-	**7 (1.5)**	**2 (0.5)**	-	4 (1.1)
Fimbristylis dichotoma	PH	**8 (1.8)**	**9 (2.8)**	-	-	4 (0.6)	2 (0.4)	10 (3.9)	10 (4.0)	8 (2.8)	8 (2.8)
Ipomoea polymorpha	AH	**8 (2.7)**	**5 (1.2)**	-	1 (0.3)	-	-	1 (0.1)	-	7 (1.3)	7 (2.2)
Lepidium phlebopetalum	AH	4 (0.7)	5 (1.1)	-	-	6 (0.9)	-	**7 (2.2)**	**10 (3.4)**	7 (2.0)	9 (1.9)
Portulaca oleracea	AH	**-**	**6 (2.0)**	10 (3.6)	10 (3.7)	9 (2.9)	5 (1.2)	**2 (0.8)**	**-**	1 (0.3)	1 (0.2)
Sida fibulifera	PH	**8 (1.7)**	**11 (3.5)**	-	1 (0.1)	2 (0.6)	4 (0.7)	2 (0.6)	-	1 (0.1)	-
Tribulus eichlerianus	AH	**10 (4.0)**	**8 (1.9)**	2 (0.3)	3 (1.0)	-	-	1 (0.2)	-	10 (3.6)	8 (2.6)

There were no significant differences in richness and abundance of life form groups (annual herbs, perennial herbs or annual grasses) or total species richness and abundance between grazed and ungrazed treatments (Table 3-5). A perennial grass (Astrebla pectinata) was present only at one dunefield site (3) in two plots, while the only other perennial grass, *Eragrostis setifolia* occurred in five plots at the floodplain site (2). The low incidence of perennial grasses precluded further analysis.

Table 3-5. Mean and 5% confidence intervals for species groups, grazed vs ungrazed

	Grazed	Ungrazed	*P*-value
Annual grass richness	5.77 (4.56-7.11)	6.00 (4.77-7.38)	0.694
Annual herb richness	5.41 (3.69-7.46)	4.91 (3.28-6.87)	0.290
Perennial herb richness	3.41 (2.66-4.25)	3.70 (2.91-4.57)	0.356
Total richness	14.96 (12.34-17.84)	14.84 (12.22-17.70)	0.933
Annual grass abundance	17.20 (12.03-23.30)	17.65 (12.38-23.84)	0.815
Annual herb abundance	13.60 (9.72-18.13)	12.65 (8.92-17.03)	0.484
Perennial herb abundance	8.48 (6.39-10.86)	9.64 (7.40-12.17)	0.296
Total abundance	40.78 (34.17-47.96)	41.17 (34.53-48.4)	0.923

At a regional scale, few species showed evidence of substantial decline associated with grazing. Of the 420 species assessed, 239 are common and widespread in the dunefields and/or floodplains of north-eastern South Australia, while a further 170 are rare or restricted in the study area but common elsewhere in rangelands subject to commercial pastoralism. Seven species (1.9% of the known flora) do not appear to be common and widespread based on the collection record and expert opinion, and were thus identified as being potentially threatened by grazing: the annual forbs *Roepera humillima*, *Gilesia biniflora*, *Calandrinia stagnensis* and *Stylidium desertorum*, the lily *Corynotheca micrantha*, perennial forb *Swainsona viridis* and shrub *Pimelea penicillaris*. The two latter species have been recorded from both floodplain and dune habitats, while the remainder are dunefield species. All other species are known to have healthy populations numbering >100 000 plants (at least in some seasons) in areas subject to commercial pastoralism.

DISCUSSION

There were no significant differences in richness or abundance of the lifeform groups between treatments after 14 years of grazing exclusion. There were also no consistent trends in the abundance or frequency of individual species between treatments. Annual life forms greatly exceeded perennials in both richness and abundance in all quadrats across all sites, and two species common at all dunefields sites, *Tripogon lolliiformis* and *Fimbristylis dichotoma*, have perennial rootstock but ephemeral stems and leaves which sprout rapidly in response to rainfall.

Annual species only establish after rainfall and rapidly replenish their seedbank (O'Connor and Roux 1995; Sullivan and Rohde 2002). We sampled in May 2010, about 100 days since the last substantial rainfall event, and all plants were flowering and seeding. Our calculations based on average stocking rates (Table 3-1) and livestock consumption (estimated at 11 kg per day, per beast, which accounts for trampling as well as consumption, R. Silcock, pers. comm., 2011) suggest that cattle could consume less than 2% of dry matter yield (averaged at 0.6 $t.ha^{-1}$, Table 3-3) across Innamincka’s dunefields in the period between germination and seeding during an exceptionally wet year. Following a wet period, stocking rates will be increased, but even using the maximum stocking rates over the past ten years (Table 3-1), cattle would consume between 5 and 6% of biomass in this 100-day period. In an average season, when yield is estimated at about 0.25 $t.ha^{-1}$ (G. Campbell, pers. comm., 2011), stock could consume about 5% of available forage. This is somewhat simplistic, given the patchy distribution of grazing across the landscape and the tendency of cattle to focus grazing in certain areas (Pringle and Landsberg 2004). Nevertheless, it serves to illustrate that with the current stock densities at Innamincka, cattle consume only a tiny fraction of plant biomass in the period between germination and plants depositing seed. These plants are able to complete their lifecycles before fodder is grazed to the extent that there is selective pressure on palatable species (Fensham *et al.* 2010a).

Even on the productive floodplain, where grazing pressure could be expected to be highest after flooding, there were no significant differences detected between grazed and ungrazed plots. Species regarded as highly palatable such as *Trigonella suavassissima* and *Tetragonia moorei* (Cunningham *et al.* 1992) did not differ significantly in abundance between treatments; both being slightly more abundant in grazed plots (Appendix 3-3). Like the dunefields, the floodplain flora is dominated by annuals, and is extremely productive after flooding and mostly devoid of groundcover during dry times (Capon and Brock 2006; Colloff and Baldwin 2010). Moreover, plants are able to set seed while these areas are still partially inundated and thus inaccessible to cattle (Phelps *et al.* 2007).

Our results suggest that the non-equilibrium paradigm is an effective description of vegetation dynamics of the dunefields and floodplains of north-eastern South Australia under current livestock grazing regimes. The ‘persistent non-equilibrium’ model of Swift and Ellis (1988) seems most applicable, where large fluctuations in forage associated with low and erratic rainfall prevent herbivore populations from tracking forage availability, therefore minimising negative feedbacks between grazing intensity and vegetation dynamics.

However, it is possible that grazing-sensitive species had been lost from the system prior to the Innamincka exclosures being erected, and did not re-establish with protection from grazing (Valone *et al.* 2002; Seymour *et al.* 2010). If the system had passed into a degraded state prior to the establishment of the exclosures, this could account for the negligible differences between treatments. At a regional scale, there are few species in the study area that show evidence of a substantial grazing-induced decline. Just seven species out of 420 recorded in these habitats do not appear to be common, widespread and regenerating at least somewhere in inland Australia subject to commercial pastoralism. Although examination of opportunistic collections cannot give insights into losses of diversity at small scales, the record does not suggest a major decline in species diversity, which would be expected with a broadscale shift to a degraded state (Fensham *et al.* 2011b). The abundance of some perennial species is limited by rainfall rather than grazing. Mitchell grass (*Astrebla pectinata*) occurred in low density at one site and exhibited no pattern in relation to grazing protection. It exhibits mass recruitment when summer rainfall exceeds about 400 mm (Williams and Mackey1983; Orr 1991), and such events are almost never likely to occur at Innamincka.

If the selective influence of grazing is affecting individual species or groups on Innamincka, it is most likely to be in more productive areas, such as floodplains and inter-dune swamps (Purdie 1984). The uneven distribution of grazing pressure means that both equilibrium and non-equilibrium dynamics can occur in plant-herbivore interactions. In particular, free-roaming herbivores may remain in equilibrium with 'key resource areas', even though they are not in equilibrium with the broad landscape matrix. These areas can delay animal mortality during drought, and are more vulnerable to degradation through long-term overgrazing (Illius and O'Connor 1999). As discussed, the 'boom-bust' nature of the floodplain flora effectively precludes the development of equilibrium dynamics and confers resilience to grazing. On the other hand, swamps and swales dominated by palatable perennial species such as Queensland bluebush (*Chenopodium auricomum*) and old man saltbush (*Atriplex nummularia*) can support cattle for extended periods, and these perennials may suffer long-term decline. Perennial shrubs have been shown to be adversely affected by grazing in other areas of Central Australia, particularly during dry periods (Barker and Lange 1969; Dawson and Ellis 1994; Friedel *et al.* 2003; Read 2004). In particular, *Atriplex nummularia* is known to decline in grazed areas, and population modelling suggests that, in the long-term, it could become locally extinct up to 2 km from water due to decreased survival and recruitment (Hunt 2001; 2010). Further data are required on the effect of grazing on the productive areas of the landscape dominated by palatable perennials. Surveys are also required to determine the vulnerability of the small number of species identified as rare and potentially threatened by grazing in the dunefields and floodplains.

The resilience of non-equilibrium environments challenges traditional understanding and management of rangelands (Illius and O'Connor 1999; Sullivan and Rohde 2002). The lack of significant differences in species richness and abundance and herbage biomass after 14 years of grazing exclusion supports this hypothesis for the dunefields of inland Australia dominated by an ephemeral flora. Both the Simpson Desert and the Innamincka dunefield are arid (less than 200 mm mean annual rainfall), although the former has had few rabbits, and has only been exposed to domestic livestock grazing for a short period. Thus there is little evidence of substantial livestock grazing effects where short exposure to grazing (30 years) can be compared with almost no grazing (Fensham *et al.* 2010a), and where short-term grazing protection (14 years) can be compared with long-term grazing (130 years) in an environment that has been subject to both rabbits and livestock grazing. The available evidence is consistent with landscapes that have not been substantially altered by grazing. These results corroborate international studies which have found little change in annual plant communities as a result of grazing, including in Mongolian shrub steppes (Fernandez-Gimenez and Allen-Diaz 1999) and the Chihuahuan Desert (Nash *et al.* 1999).

Our results suggest that the north-eastern South Australian rangelands are self-regulating, annual-driven systems, where stock can be supported following rain but must be moved off as the forage disintegrates in dry times. If this does not occur the grazing animals will rapidly lose condition and eventually starve. Many studies suggest that the sustainability of non-equilibrium rangelands is dependent upon drought periodically decreasing livestock numbers (Ellis and Swift 1988; Oba *et al.* 2000; Vetter 2005). In an Australian context, this emphasises the importance of mobility over large spatial scales and flexible stocking rates. Large companies own much of the land in the north-eastern South Australia and south-western Queensland, meaning that cattle can be shifted from drought affected properties before they perish in the face of declining forage. While recent studies (Fensham *et al.* 2010a; Fensham *et al.* 2011b) have indicated that some widespread ecosystems may be more resilient to livestock grazing than previously thought (Friedel 1997; Read 1999; Friedel *et al.* 2003; Landsberg *et al.* 2003), there is a requirement for more research to identify potentially sensitive elements of the vegetation in the Australian arid lands.

CHAPTER 4.

ASSESSING RARITY AND THREAT IN AN ARID ZONE FLORA

INTRODUCTION

Understanding the link between rarity and extinction risk is fundamental to conservation biology. Biological rarity is simply defined as the state of having low abundance and/or small range size (Preston 1948; Kunin and Gaston 1993). However, rarity is a relative and scale-dependent concept, and there have been numerous attempts to elucidate different forms of rarity (Reveal 1981; Fielder and Ahouse 1992; Gaston 1994). The most influential of these remains the Rabinowitz framework, which expresses plant rarity as a combination of three attributes: geographic distribution, habitat specificity and local population size (Rabinowitz 1981; Rabinowitz *et al.* 1986). Although these traits are really continuous variables, when each attribute is dichotomised, eight combinations emerge. All except one (wide geographic range, broad habitat specificity, large population size) can potentially contain rare species.

While rarity can predispose species to external threats and stochastic events (Coates and Dixon 2007; Flather and Sieg 2007), some species are rare without being threatened (Morse 1996). Formal assessment of a species' conservation status integrates the concepts of rarity and endangerment by considering both inherent demographic characteristics and perceived level of threat or evidence of population decline (Butchart 2003; Williams 2006). The legal status assigned to species is published in threatened species lists, which underpin conservation planning and prioritisation (McIntyre 1992; Joseph *et al.* 2007). Despite their centrality to conservation efforts, the limitations and biases of threatened species listing processes are well recognised (Blackburn and Gaston 1997). In particular, there are concerns that current lists remain biased towards naturally restricted species at the expense of relatively widespread species that may be at greater risk from current threats (McIntyre 1992; Burgman 2002).

Numerous studies have examined patterns of rarity and threat in regional floras (Hall 1987; McIntyre 1992; Mokany and Adam 2000; Broennimann *et al.* 2003; Loranzo *et al.* 2003; Landsberg and Clarkson 2004; Zhang and Ma 2008), including in semi-arid and arid areas (Parsons and Browne 1982; BoRong and LingKe 1995; Hernandez and Barcena 1996; Khan *et al.* 2003; Stohlgren *et al.* 2005; Singh *et al.* 2007). However, there has been no detailed examination of how these concepts play out in the desert biomes of the world. Arid areas are characterised by generally low collection effort spread over vast expanses, temporal variability and ill-defined threats, all of which must be considered in any assessment of rarity and threat.

Existing frameworks and classifications tend to consider rarity as a spatial phenomenon, and generally do not address temporal components of rarity (Harper 1981). While temporal rarity occurs in all floras to some extent, it is likely to be especially prevalent in arid zone vegetation which is driven by episodic and unpredictable rainfall events, interspersed with long dry periods (Noy-Meir 1973; Morton *et al.* 2011). To cope with this variability, many annual plants and geophytes have the ability to remain dormant in the soil, completing their life cycles rapidly in response to favourable conditions (Jurado and Westoby 1992; Bell 1999; Holgrem *et al.* 2006). Species that are absent or rare in the standing vegetation for much of the time may become common in certain seasons (Capon and Brock 2006; Porter *et al.* 2007). For these species, conditions conducive to germination may involve complex cues and occur infrequently (Maconochie 1982; Ogle and Reynolds 2004; Wei *et al.* 2009). It is also possible that some species are associated with particular post-disturbance successional stages, following fire, extended dry periods or anthropogenic disturbance (Murray *et al.* 1999; Kirkpatrick 2007). Thus the apparent rarity of some short-lived species may be an artefact of their life history strategy, rather than limited range or abundance.

Detecting genuine rarity in the arid zone is further confounded by the low intensity of botanical collections, particularly for smaller and less conspicuous plants in inaccessible or remote areas (Hall 1987; Pearce and Bytebier 2002). For temporally rare species in relatively unvisited areas, the chance of a collectors' visit coinciding with a 'boom' event for that particular species is very low. Finally, in contrast to highly modified landscapes, where threats such as habitat destruction, weed invasion, dieback and salinity are obvious and often severe (Woolley and Kirkpatrick 1999; Hobbs *et al.* 2003; Burgman *et al.* 2007; Shearer *et al.* 2007), the threats to rare plants in arid areas tend to be diffuse, subtle and poorly understood (New South Wales National Parks and Wildlife Service 2000; Woinarski and Fisher 2003). For example, the intensification of livestock grazing with an extensive network of artificial waters in the Australian arid-zone has been proposed as a potentially threatening process (James *et al.* 1999). However, a more recent review of studies searching for species that exhibit a strong association with water-remote habitat indicated that the findings are inconclusive and failed to identify threatened plant species associated with these habitats (Fensham and Fairfax 2008).

This study aims to provide a framework for systematically reviewing rarity and threat in the flora of a remote semi-arid and arid region. The status of all species occurring in the study area was assessed, and a list of rare and potentially threatened species was developed by combining the existing threatened species register with currently unlisted species identified as being potentially rare and threatened (hereafter referred to as 'candidate species'). The composition of these two lists was examined for potential patterns and biases in rarity forms, life form, habitat and geographic distribution through comparison with the entire flora. Threatening processes were scored for currently listed species and groups of species that exhibited similar 'threats syndromes' (Burgman *et al.* 2007) were identified. The patterns of rarity and threat, as well as inconsistencies and knowledge gaps, will be used to provide recommendations for future research into plant conservation in arid zones. It will also underpin a survey program to identify the most threatened species in the study area and the management actions that are required to ensure their persistence.

METHODS

Study area

The Mulga Lands, Mitchell Grass Downs and Channel Country (here considered to include the Simpson-Strzelecki Dunefields) biogeographic regions (Thackway and Cresswell 1995) in Queensland form the target of this study (Figure 4-1). The Mulga Lands contain the most extensive tracts of mulga (*Acacia aneura*) shrubland in Queensland (Dawson and Ahern 1973). The channels and floodplains of the Channel Country are interspersed with a matrix of stony plains, open downs, shrublands, and linear dunefields of the Simpson and Strzelecki Deserts in the far south-west (Wilson *et al.* 1990). The Mitchell Grass Downs are characterised by open clay soil plains dominated by *Astrebla* species (Turner *et al.* 1993). All three bioregions are intersected by low sandstone ranges. The climate ranges from semi-arid to arid, with rainfall characterised by high variability, and average values decreasing on an approximately south-west gradient from just over 500 mm along the eastern and north-eastern boundary to 120 mm in the Simpson Desert. Summer temperatures are hot with maximum temperatures throughout December-February averaging 35°C, while short winters are characterised by cold nights often falling below zero and warm days averaging 20°C. The majority of the study area is used for extensive cattle and, in the eastern portion, sheep grazing, with relatively small areas occupied by mining leases and conservation reserves.

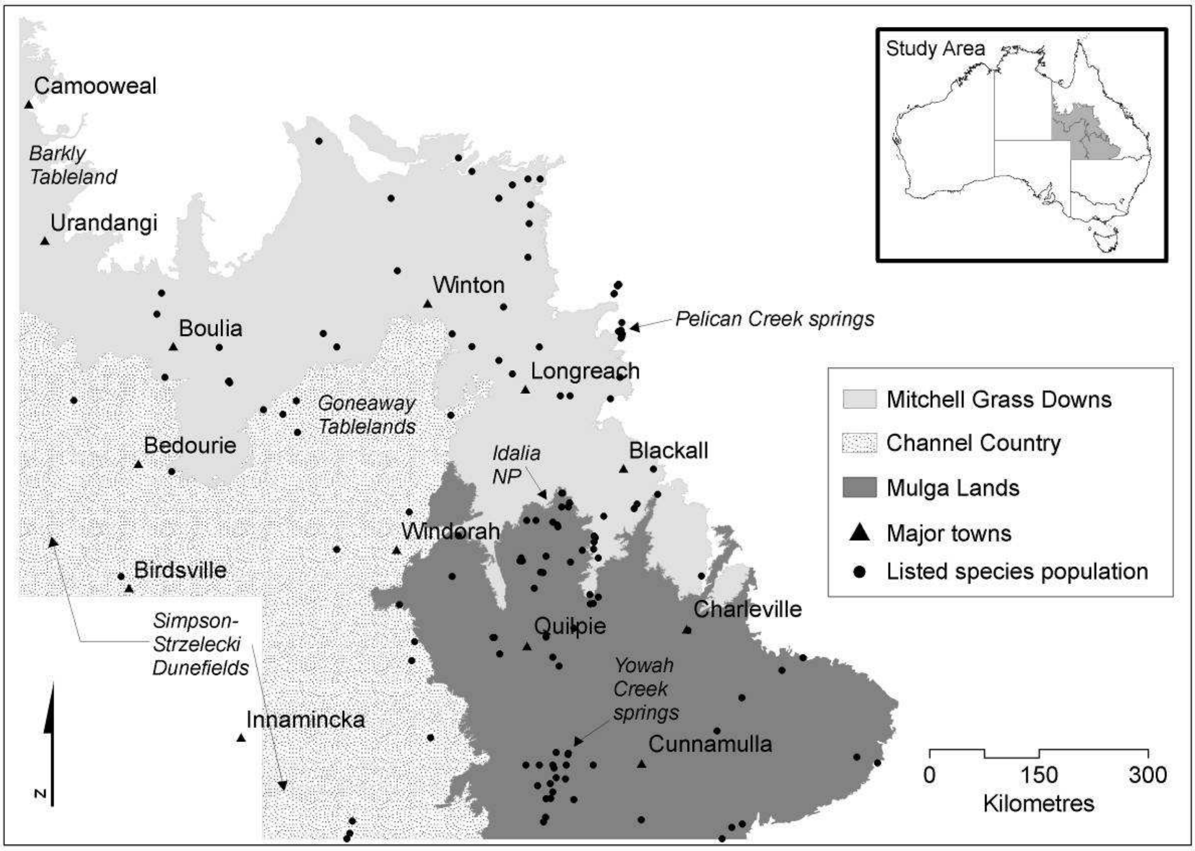


Figure 4-1: Western Queensland study area, showing bioregions, major towns, places referred to in text and populations of listed species. Only one record from each population is included. Records separated from another occurrence by more than 10km and/or a patch of unsuitable habitat are considered separate populations.

The methodology for examining rarity and threat in the study area involved four components: (i) develop a database of rare and potentially threatened species, using the existing threatened species register plus a systematic trawl through the flora to identify extra species for a candidate list (ii) assign all species occurring in the study area to a form of rarity after Rabinowitz (iii) assess the current and candidate lists by life form, habitat and threats (current list only) (iv) identify forms of rarity and life forms that may have been overlooked in the listing process.

Developing candidate list of ‘rare’ species

Forty-four plant species are currently listed as Near Threatened (formerly Rare), Vulnerable or Endangered under Queensland’s *Nature Conservation Act (NCA) 1992* in the area defined above as western Queensland (Department of Environment and Resource Management 2010). Any person can nominate a species for listing, and the threat status of a nominated species is assessed by a Species Technical Committee against IUCN Red List criteria, based on population parameters, evidence of decline and the magnitude of current threats (IUCN 2001). Most species listed as Vulnerable or Endangered in Queensland are also recognised under the national *Environmental Protection and Biodiversity Conservation Act (EPBC) 2001*.

In recognition of the limitations and biases of the threatened species listing process, including the fact that genuinely rare species can go undetected (McIntyre 1992; Landsberg and Clarkson 2007), a thorough examination of the western Queensland flora (here called the ‘trawl’) was undertaken to detect unrecognised but potentially rare and threatened species. A list of all species occurring in the study area was generated using the Queensland Herbarium’s electronic flora base mapping program, BriMapper (Bostock 2010). This list was pruned by removing all introduced species and erroneous records, leaving a total of 1781 species (including numerous undescribed taxa). Each species was assigned to one of 10 categories (Table 4-1), based on published information, Queensland herbarium records, online herbaria, and expert and personal knowledge. Assessments were based on the total geographic range of a species. Plants categorised as 1-3 are widespread and common in the study area; categories 4-6 are uncommon or restricted in the study area but common elsewhere. Rarity alone is not a sufficient predictor of extinction risk (Gaston 1994), hence those species assigned to category 7 are restricted in range or habitat, but are not considered by relevant experts to meet IUCN Red List criteria.

Table 4-1. Categories assigned in the trawl for western Queensland flora

Category	Geographic distribution and threat status
1	Widespread and common in study area and elsewhere in and outside the arid zone
2	Widespread and common in study area and elsewhere in arid zone only
3	Widespread and common in study area but not elsewhere (western Queensland endemic)
4	Uncommon or restricted in study area, but more common to east or north (primarily tropical species)
5	Uncommon or restricted in study area, but more common in southern Australia
6	Uncommon or restricted in study area, but more common in arid zone of other Australian states
7	Restricted range or habitat, but abundant within this range and no known threats
8	Currently listed species (Endangered, Vulnerable or Near Threatened)
9	Potentially threatened ('candidate species' for this study); includes currently undescribed species that are considered distinct taxa by relevant experts
10	Unnamed/undescribed collections; taxonomy remains uncertain

Species were deemed to be potentially rare (category 9) if they met one or more of the following criteria: (a) known from <10 populations or very restricted range or habitat, (b) not collected in study area in the past 20 years, (c) some records in study area likely to be a new or undescribed species that is restricted or rare, and/or (d) apparent declining population trend, or suspected threat to plant or habitat. Category 9 species were checked with relevant experts, mostly curators from the Queensland Herbarium responsible for individual plant families and botanists from Herbaria in other states, and a decision was made to either retain the species as potentially threatened or place it in another category (e.g. restricted but no cause for concern). In the absence of knowledge of potential threats, and where a species was known from few collections, a precautionary approach was taken, and the species was retained as category 9 pending further surveys or information. The taxonomy of 34 species was considered to be uncertain after discussions with relevant experts; these were assigned a category 10 and excluded from further analysis.

Forms of rarity

The 1747 taxonomically certain species occurring in the study area were classified as displaying a form of rarity, based on the three traits of Rabinowitz *et al.* (1986) (Table 4-2). Geographic distribution was assessed using Queensland Herbarium records, Australian Virtual Herbarium, online herbaria of other states (New South Wales and Western Australia) and distribution maps in taxonomic treatments (e.g. Flora of Australia). Habitat specificity and local population size were assessed based on information contained in herbarium specimen labels, field guides (Allen 1949; Cunningham *et al.* 1992; Milson 2000a and b; Jessup 1981) and electronic resources (Maslin 2001; Sharp and Simon 2002), taxonomic treatments, and personal and expert knowledge. The representation of the different forms of rarity on the current register of threatened flora and the candidate list were compared with the overall flora.

Table 4-2. Forms of rarity after Rabinowitz (1981), defined here for application of the flora of western Queensland. Wide, occurs across an area >10 000 km^2; Narrow, restricted to an area <10 000 km^2; Broad, occurs across numerous habitat types; Restricted, Confined to one broad habitat type; Somewhere large, common or abundant in at least some situations; Everywhere small, always sparse or occasional where it occurs.

Geographic distribution	**Wide**		**Narrow**	
Habitat specificity	*Broad*	*Restricted*	*Broad*	*Restricted*
Local population somewhere large				
	Common	R1	R4	R5
Local population everywhere small				
	R2	R3	R6	R7

Data collation and analysis for listed and candidate species

Available information on the 44 currently listed species and 62 candidate species was collated, and they were analysed using Chi-square tests for life form (McIntyre 1992) and habitat, and qualitatively using ArcGIS software for geographic distribution. Broad habitat types were defined through merging land systems in Western Arid Region Land Use Study mapping (Division of Land Utilisation 1974, 1978 & 1979; Mills *et al.* 1990; Wilson *et al.* 1990; Turner *et al.* 1993) (Table 4-3). Where species were common across more than one habitat type, broad preference was classified as variable. Species records were checked for spatial accuracy and entered into an ArcMap9.3 database. Threats were only analysed for currently listed species, as the limited information available on most candidate species precluded any meaningful assessment.

Table 4-3. Broad habitat types, western Queensland

Habitat Type	Description
Acacia woodland	Open woodland on light clay or loamy soils, often with surface pebbles, including *Acacia cambagei, A. georginae, A. tephrina* and *A. harpophylla*
Springs wetlands	Great Artesian Basin spring wetlands
Scald habitats	Includes groundwater scalds near Great Artesian Basin springs, as well as bare scalds on saline-sodic or gypseous soils
Downs	Treeless plains on cracking clay soils; includes open grasslands (mostly dominated by *Astrebla* species) and ephemeral herbfields
Dunefields	Aeolian sand dunes, including linear sand ridges of the Simpson and Strzelecki Deserts and stabilised, degraded dunefields of the southern Mulga Lands
Other wetlands	Landforms, excluding spring wetlands, that are regularly or sporadically inundated including floodplains, claypans, gilgais and waterholes
Limestone	Limestone geology of the Georgina Limestone formation in the north-west of the study area, including limestone grasslands and outcrops
Residuals	Tertiary sandstone ranges (encompassing mesas, slopes, plateaux, toeslopes), and low hills and gibber plains of the Channel Country
Sandy red earth	Sandy and sandy-loam red soils in the Mulga Lands, supporting *Acacia aneura* or mixed *Eucalyptus/Acacia* woodlands or shrublands, sometimes with an understorey of spinifex (*Triodia* spp.)

Threatening processes fall into two broad categories. Extrinsic threats originate from outside the organism and are often anthropogenic, while intrinsic threats result from the unique biology of a species, which can make it susceptible to external pressures (Given 1994). Relevant threats to each species were identified through published information, expert interviews and personal observations. Scoring for demographic factors was modified from Williams (2006) and Burgman *et al.* (2007) (Table 4-4). A population was considered 'extant' if there is a herbarium record within the past 10 years, or if it is known by the author or others. Range size encompassed only currently known populations. Anthropogenic threats were split into observed (based on recent field observations by the authors or others, score 2) and suspected (based on anecdotal or published information, score 1) (Table 4-4). Species were assigned to one of five threat syndromes based on biogeography and threatening processes: shrubs from residual habitats, aquatic forbs from springs, long-lived trees and shrubs restricted to a few populations, short-lived species with sporadic germination, and widespread but sparse species known from few collections.

Table 4-4. Threatening processes for listed plants in western Queensland (modified from Williams 2006 and Burgman *et al.* 2007)

Threatening Process	Explanation/Definition	
Demographic factors	**Score = 1**	**Score = 2**
Few extant populations	6-15 populations	<6 populations
Small range	100-1000km^2	<100km^2
Narrow habitat	Known from two habitat types (see Table 4-3)	Known from only one habitat type
Lack of current recruitment	Lack of recruitment mentioned anecdotally, but no recent field observations	Demonstrated lack of recruitment (either seedling or vegetative) based on recent field observations
Anthropogenic factors	**Suspected (=1)**	**Observed (=2)**
Herbivore impacts (includes grazing, browsing and/or trampling by domestic, feral or native animals)	Palatable species in a habitat grazed, browsed or trampled by domestic, feral and/or native herbivores; threat suspected but not supported by field observations	Demonstrated threat from grazing, browsing or trampling, based on field observations; i.e. plants preferentially grazed
Changed fire regimes (extent, intensity or frequency)	Suspected or anecdotal threat to plant or habitat from changed fire regimes, but not backed up by field observations	Fire kills plant and does not initiate germination
Groundwater extraction	n/a	Diminished aquifer pressure due to groundwater extraction, leading to loss of springs habitat (see Fairfax and Fensham 2002)
Excavation	Suspected or possible future threat to habitat or plant from excavation (includes excavation of springs and mining activities)	Observed threat to plant from excavation (includes excavation of springs and mining activities)
Weeds/competition	Suspected threat to plant or habitat from invasive species	Observed threat to plant from invasive species

RESULTS

Flora trawl

Most of the 1781 species are common and widespread in the study area and elsewhere (categories 1 and 2, 36%) or uncommon in the study area but more common and widespread elsewhere in Australia (4-6, 50%) (Table 4-5). Only 22 species (1% of the total flora) are mostly confined to western Queensland. Around 5% of species are restricted in range and/or habitat without meeting IUCN Red List criteria (category 7). The 44 currently-listed species represent 2% of the western Queensland flora. The trawl identified a further 62 candidate species that are potentially threatened and warrant further investigation (Appendix 4-1).

Table 4-5. Trawl categories in western Queensland flora (defined in Table 4-1)

Trawl category	Number of species (Total)	% of species	Cumulative totals	
1	391	22	Common in study area and elsewhere	36%
2	249	14		
3	22	1	Restricted to western Queensland	1%
4	527	30	Uncommon in study area but common elsewhere	50%
5	167	9		
6	187	11		
7	97	5	Restricted distribution	5%
8	44	2	Currently listed or potentially threatened (candidate species)	6%
9	62	4		
10	34	2	Taxonomic uncertainty	2%
TOTAL	*1781*	*100*		*100%*

Forms of rarity

Over half of western Queensland species (912, 52%) are classified as 'common' (C) under the Rabinowitz framework (Table 4-6). None of these are currently listed and only *Sauropus ramossissimus* was identified as a candidate species, due to not having been collected in the study area in the past 20 years. Almost 30% are confined to a specific habitat but were widespread and abundant within this habitat (R1). This form of rarity accounts for 23% of listed species, including two listed as Endangered (the spring-dependent species *Myriophyllum artesium* and *Eriocaulon carsonii*). Widespread but sparse species (R2 and R3) are uncommon in the flora, and just three of these species are currently listed. However, a further 10 were identified as potentially threatened in the trawl. Twenty-five of the 44 currently listed species (57%), and 26 candidate species (41%) have narrow geographic ranges and restricted habitat (R5), but represent only 6% of the total flora. Narrow range species with small populations (R6 and R7) represent the most uncommon forms of rarity in the western Queensland flora (together comprising 1.5% of the flora), but account for 12% of listed species. In addition, nearly all unlisted species displaying this form of rarity were identified as potentially threatened in the trawl.

Table 4-6. Representation of forms of rarity in western Queensland flora, current list and candidate list

	Total flora		Listed species		Candidate species	
Form of Rarity	**Number spp.**	**% of total flora**	**Number spp.**	**% of listed species**	**Number spp.**	**% of candidate species**
C	912	52	0	0	1	1.5
R1	505	29	10	23	6	10
R2	97	6	1	2	5	8
R3	44	2.5	2	4.5	4	6
R4	56	3	1	2	3	5
R5	105	6	25	57	26	42
R6	7	0.5	2	4.5	3	5
R7	20	1	3	7	14	22.5
TOTAL	*1746*	*100*	*44*	*100*	*62*	*100*

Almost 90% of western Queensland species have wide ranges, but 65% of listed and 69% of candidate species are geographically restricted (Table 4-7). Around 90% of candidate species are habitat restricted, compared with just 39% of the overall flora. Most western Queensland species occur in large numbers somewhere, with only 9% classified as having populations ‘everywhere small’. However, 42% of candidate species were classified as everywhere small, compared to just 16% of currently listed species.

Table 4-7. Percentage of all, listed species and candidate species assigned each rarity parameter

	Total flora	Listed species	Candidate species
Geographic distribution			
Narrow	11	65	69
Wide	89	35	31
Habitat			
Restricted	39	93	88
Broad	61	7	12
Local population size			
Everywhere small	9	16	42
Somewhere large	91	84	58

Biogeographic analysis of listed and trawl species

Shrubs comprise 14% of the western Queensland flora and 21% of listed species, while aquatic forbs comprise just 2% of the flora but account for 11% of listed species (Table 4-8). Trees are also slightly over-represented relative to their occurrence in the flora. Grasses, perennial forbs and sedges are proportionally under-represented in the current list. The candidate list is dominated by forbs (49% of trawl list, 12 annuals and 21 perennials), while a further 20% of candidate species are grasses.

Table 4-8. Proportion of species of each life form class (PF=perennial forb, AF=annual forb, PG=perennial grass, AG=annual grass, Aq=aquatic forb; other includes ferns, lilies, mistletoes and orchids; Chi-square = 33.90 with d.f.=16, p<0.01)

	Tree	Shrub	Vine	PF	AF	PG	AG	Sedge	Aq.F	Other
Listed species	11	21	2	23	25	5	0	2	11	0
Candidate species	6	11	3	32	19	9	10	3	2	5
Regional flora	8	14	3	30	23	10	4	4	2	2

Together, wetlands and residual habitats (Table 4-3) account for 57% of all listed species. Sixteen percent of listed species are restricted to spring wetlands, despite comprising just one percent of the flora, including six of the nine Endangered species (Table 4-9). Nine percent of the total flora and 41% of listed species, including over half of all vulnerable species, are restricted to residual habitats. Three listed species occur on sandy red earths in the Mulga Lands, while five (including two of the three Endangered species that do not occur in spring-fed habitat, *Oldenlandia spathulata* and *Austrobryonia argillicola*) are restricted to cracking clay downs. Residuals also accounted for almost one-third of candidate species (Table 4-9). *Acacia* woodlands (8%), limestone formations (5%) and sandy red earths (11%) account for a higher proportion of candidate than listed species. Spring wetlands contain five candidate species, mostly undescribed taxa, while a further four species occur on groundwater scalds in the vicinity of springs.

Table 4-9. Broad habitat preferences, western Queensland flora (Chi-square=318.5 with d.f.=18, p<0.001)

Habitat	Total flora		Listed species		Candidate species	
	Number spp.	% of total flora	Number spp.	% of listed species	Number spp.	% of candidate species
Acacia woodlands	19	1	1	2	5	8
Springs wetlands	21	1	7	16	5	8
Scald habitats	25	1	2	5	4	6
Downs	101	6	5	11	7	11
Dunefields	43	3	0	0	0	0
Other wetlands	222	13	3	7	5	8
Limestone	9	1	1	2	3	5
Residuals	160	9	18	41	19	31
Sandy red earths	85	5	3	7	7	11
Variable	1062	61	4	9	7	11
TOTAL	*1746*	*100*	*44*	*100*	*62*	*100*

Of the three bioregions analysed, the Mulga Lands contain the highest proportion of threatened species (60% of all listed species in western Queensland). The Mitchell Grass Downs and Channel Country contain 54% and 40% of listed species respectively. Many species occur across two or three bioregions. The exceptional concentration of endemism in a single Great Artesian Basin springs complex on the eastern edge of the Mitchell Grass Downs (Pelican Creek springs, Figure 4-1) includes eight listed and five candidate species. Aside from this, the largest numbers of threatened species occur in a band through the central-western Mulga Lands, with large clusters of records in Idalia National Park (seven species, six from residual habitats) and in a triangle south-west of Cunnamulla, where numerous habitat types including springs, ranges and floodplains intersect (Figure 4-1).

All other regions are characterised by relatively sparse records of listed species. The highest concentration of threatened species in the Channel Country occurs in the residual habitats of the Goneaway Tablelands south-west of Winton. The open plains of the Channel Country and Mitchell Grass Downs, including clay soil grasslands and gibber plains, have low densities of listed and candidate species. No listed species have been collected from most of the western quarter of the region, which includes the Simpson and Strzelecki dunefields in the south-west and the open grasslands of the Barkly Tableland in the north (Figure 4-1). The geographic distribution of candidate species is more even across the region, however similar clusters are evident from the residuals of the Mulga Lands. The Barkly Tableland in the far north-west (0 listed species) contains five candidate species. However, other large regions with few listed species have similarly low numbers of candidate species, including the Simpson and Strzelecki Dunefields, northern Mitchell Grass Downs and the sandy red earths of the eastern Mulga Lands.

Threatening processes

Threats were considered only for listed species, due to a lack of information about most trawl species. All bar one listed species can be considered 'threatened' by virtue of demographic factors (Table 4-4) while there is a suspected external threat to 33 listed species (75%). However, an external threat has been observed for only twelve of these species, including nine spring species. Thus demographic factors form the basis for the majority of species listings. Specifically, 17 species are known from fewer than six populations (score 2, Table 4-4), and a further 19 are known from between six and 15 populations (score 1) (Figure 4-2). Most listed plants have narrow habitat requirements, however only spring species have a very restricted geographic range (<100 km^2). Long-term lack of recruitment has been observed as a threat to two species (*Acacia ammophila*, Mark Handley, pers.comm., August 2007 and *Grevillea kennedyana*, NSW National Parks and Wildlife Service 2000), but is suspected for a further six. This may be an underestimate due to lack of knowledge of population structure and dynamics for most species.

There was no demonstrable link between most suspected threatening processes and decline of a species. Herbivore impact (including grazing, browsing and tramping) is the most common suspected threat to listed species in western Queensland, with both domestic and feral animals regarded as potential threats to over half of listed species (Figure 4-2). While feral animals has been observed as a threat after surveys for eleven species (pigs for the nine springs species, goats for *Xerothamnella parvifolia* and *Rhaphidospora bonneyana*), domestic grazing is an observed threat to just one listed species (sheep grazing, *Acacia ammophila*). Macropod grazing pressure has potential to affect around one-third of listed species, however a threat has only been observed in two cases (also *X. parvifolia and R. bonneyana*, pers.obs.). Published information suggests that altered fire regimes may potentially threaten ten species (Environment Australia and QPWS 1999). Groundwater extraction (historically), excavation and introduced sown pasture species are observed threats to all spring-dependent species. Excavation for gypsum mining is a suspected threat to one species (*Eremophila tetraptera*).

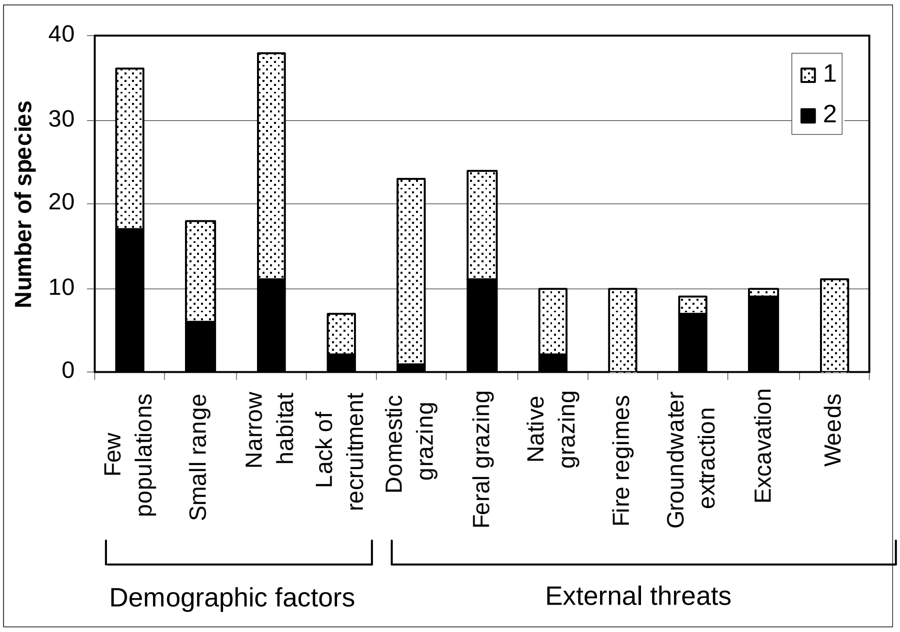


Figure 4-2. Number of listed species threatened by demographic and external threats (see table 4-4 for definitions of threats and scoring system)

Examination of biogeographic traits and threatening processes for listed species, suggests five 'threat syndromes' for the western Queensland flora (Table 4-10). Residual and spring endemics account for almost half of all species (syndromes 1 and 2), and are the best understood syndromes. Six long-lived perennial species are restricted to few populations, although often occurring across numerous habitat types (threat syndrome 3). They possibly represent relict populations of species that were more widespread under past climates. As such, they are vulnerable to localised impacts, for example elevated grazing pressure and a consequent lack of recruitment. Threat syndromes 4 and 5 are closely related, and numerous species could be placed in either category. Where rainfall records, collection patterns and expert knowledge indicated some degree of temporal rarity or boom-bust population dynamics, species were placed in syndrome 4. Species categorised to these threat syndromes are known from few collections and specific threats are not well-understood.

Table 4-10. Summary of threat syndromes in the western Queensland flora. Note the sedge *Eleocharis blakeana* and daisy *Brachyscome tesqorum* could not be assigned, and both are relatively common outside the study area

Syndrome	Characteristics and suspected threats	Species
1. Residual endemics (11 spp.)	Species adapted to isolated residual habitats (at least in study area), with naturally few populations and relatively restricted range; potentially threatened by goat and macropod grazing pressure	*Acacia spania, Euphorbia sarcostemmoides, Grevillea kennedyana, Hakea maconchieana, Indigofera oxyrachis, Melaleuca kunzeoides, Micromyrtus rotundifolia, Ptilotus maconochiei, Rhaphidospora bonneyana, Thryptomene hexandra, Xerothamnella parvifolia*
2. Springs endemics (9 spp.)	Endemic to GAB discharge springs, resulting in few isolated populations; threats include habitat destruction through aquifer drawdown, excavation of habitat feral pig damage and introduced pasture spp.	*Calocephalus* sp. (Eulo), *Eriocaulon aloefolium, E. carsonii, E. giganticum, Eryngium fontanum, Hydrocotyle dipleura, Myriophyllum artesium, Sporobolus pamelae, Sporobolus partimpatens*
3. Long-lived shrubs/ trees (6 spp.)	Long-lived trees and shrubs, possibly relictual, restricted to a few populations; inherently vulnerable to localised threats	*Acacia ammophila, Acacia crombiei, Acacia peuce, Cadellia pentastylis, Cerbera dumicola, Eremophila tetraptera*
4. Short-lived species (10 spp.)	Poorly-collected, known from only a handful of records; apparent rarity possibly due to sporadic germination; specific threats not well understood	*Actinotus paddisonii, Atriplex lobativalvis, Austrobryonia argillicola, Calotis suffruticosa, Oldenlandia spathulata, Picris barbarorum, Ptilotus brachyanthus, P.pseudohelipteroides, Rhodanthe rufescens, Sclerolaena walkeri*
5. Sparse species (6 spp.)	Occur sparsely across the landscape and are currently known from very few collections; specific threats not well understood	*Elacholoma hornii, Goodenia angustifolia, Sclerolaena blackiana, S. blakei, Vittadinia decora*

DISCUSSION

Potential biases in list

Three broad trends are evident through comparing the composition of the current list with the candidate list and total flora: a dominance of narrow endemics, under-representation of widespread but sparse species, and an absence of grasses in the current list. Species with narrow geographic ranges and restricted habitats but large populations where they do occur (form of rarity R5, Table 4-2) comprise 6% of the western

Queensland flora, but 57% of the current threatened species list (Table 4-6). The predominance of restricted endemics in numerous threatened species lists (McIntyre 1992; Adam 2000; Burgman 2002) indicates either that locally endemic species experience the greatest degree of threat (Rabinowtiz *et al.* 1986), or that there is a tendency to list species which show the most obvious pattern of rarity (Mokany and Adam 2000).

Perennial forbs and shrubs from residual habitats and aquatic forbs from spring wetlands dominate the western Queensland threatened species list, reflecting the concentration of specialised endemics in these habitats. Aquatic forbs and shrubs account for just 2% and 14% of the regional flora but make up 11% and 21% of threatened species list, respectively. The listing of species from springs is certainly justified given their restricted habitat that has been devastated since European settlement (Fensham and Fairfax 2003; Fensham and Price 2004). Mountain ranges are recognised as important refugia (Fjeldsa and Lovett 1997) and many ranges across inland Australia harbour rare and specialised species (Crisp *et al.* 2001; Preece *et al.* 2007; Byrne *et al.* 2008). At least in western Queensland, some of these may be genuinely restricted and potentially threatened, especially long-lived perennials, which can be vulnerable to long-term grazing pressure (Landsberg *et al.* 1997; Hunt 2001). However, others occur across relatively wide areas, in large populations and are not known to be under threat. The listing of such species may reflect the fact that they are easy to document and classify (Burgman *et al.* 1995).

In contrast, the listing processes may under-represent species that are more difficult to document, especially widespread but sparse species (McIntyre 1992; Burgman 2002). A major discrepancy between the current and candidate lists is in local population size, where ‘everywhere small’ species comprise 19% of the current list, but almost half of the candidate list. This suggests that numerous sparse species may have been overlooked by the current listing process. Although everywhere-sparse species will not necessarily be threatened (Murray *et al.* 1999), there are grounds for concern about their long-term persistence in landscapes subject to extensive grazing pressure. Lange and Willcocks (1980) showed that domestic herbivores have the capacity to rapidly eliminate scattered populations of small, scarce plants. Listing of widespread species under IUCN criteria depends upon being able to demonstrate evidence of decline of the species (Keith 1998). The lack of any suitable monitoring across most of the worlds' arid zones means that widespread but sparse species could decline unnoticed. This situation is compounded because Herbarium records are the only baseline data on the distribution, occurrence and life history of nearly all sparse species. While emerging statistical techniques permit inferences to be drawn about rates of decline and probability of extinction based on sightings and search effort (e.g. Burgman *et al.* 1995; Solow 2005; Collen *et al.* 2010), such models will be unreliable if used in isolation for arid zone plants, where the collection record is sparse and the absence of a species at a site at a particular time does not mean that it is not present as dormant propagules.

Grasses comprise 14% of the regional flora but just five percent of listed species (Table 4-8). Only two grasses, both spring endemics, are currently listed in Queensland. Either the biology of grasses renders them less susceptible to being restricted and threatened (Hartley and Leigh 1979), or they have been overlooked in the listing process. Grasses comprise a sizeable proportion of domestic stock and macropod diets (Griffiths and Barker 1966; Dawson and Ellis 1994). Moreover, consistent grazing pressure is thought to have reduced the abundance of perennial grasses, particularly palatable species, throughout the semi-arid zone (Grice and Barchia 1992; Anderson *et al.* 1996). In extreme cases, palatable perennial grass species can be completely eliminated from large areas (Fensham *et al.* 1999). Concern for the long-term persistence of palatable grasses in an extensively grazed landscape might therefore be justified. Examination of Herbarium records shows that grasses are relatively poorly-collected in western Queensland post-1980, and eight of the twelve candidate grasses were highlighted simply because they have not been collected in the study area for 20 years. Targeted surveys based on historical collection localities following good summer rainfall have the potential clarify the conservation status of these species.

While sedges are under-represented in the current list compared to their prevalence in the total flora, few sedges were identified in the trawl, suggesting that most sedges are indeed widespread, common and not considered to be at risk. Forbs comprise the majority of the candidate list, indicating that some may have been overlooked in the listing process. Lilies and vines are represented by only a handful of species in the western Queensland flora, but account for relatively high proportions of candidate species (Table 4-8). Their apparent rarity may be due to their life cycles including periods of dormancy, coupled with the fact that some occur in poorly-collected areas.

Hotspots and threat syndromes

The identified 'threat syndromes' in the western Queensland flora (Table 4-10), combined with the clustering of threatened species in space (Figure 4-1), provide opportunities for management actions that can result in favourable outcomes for multiple species (Coates and Atkins 2001; Burgman *et al.* 2007). Such targeted efforts can be effective, as demonstrated by recent efforts to protect the listed species occurring in western Queensland springs. The conservation values of these springs are well-recognised (e.g. Fensham *et al.* 2004; Ponder and Slatyer 2007; Fairfax *et al.* 2007) and are re-iterated here, particularly for Pelican Creek springs comprising about 6 hectares of wetland habitat with eight listed and six candidate species, and Yowah Creek springs with 2.6 hectares of habitat containing four listed and two candidate species. The importance of western Queensland residual habitats to plant conservation is also highlighted. Field surveys in hills and ranges have the potential to extend the ranges and known populations of listed and candidate species, allowing a more accurate assessment of their threat status (Keith 2000; Keighery *et al.* 2007).

The paucity of listed species from sandy red earths, dunefields, downs, gibber plains and *Acacia* woodlands seems anomalous, given the predominance of these habitat types across much of western Queensland. All have been subject to broad-scale changes since pastoral settlement (James *et al.* 1999; Woinarski and Fisher 2003), and the sandy red earths of the Mulga Lands are thought to be particularly degraded (Mills 1989; Baker *et al.* 1992). In particular, very few areas are now far enough from water to be ungrazed (Fensham and Fairfax 2008). Induced rarity has been ascribed to high levels of dietary selection exercised by herbivores, even at low stocking rates (Lange and Willcocks 1980; Williams 1981). If potentially vulnerable species from these habitats have been overlooked in the listing process, they should have been identified by the systematic trawl. Sandy red earths, downs and *Acacia* woodlands on clay were all better-represented in the candidate than in the current list, suggesting that some species from these habitats have been overlooked. However, our results indicate that the vast gibber plains and dunefields of western Queensland have relatively few restricted species.

It is vital to quantify the magnitude and nature of threatening processes to be able to pursue any management actions (Williams 2006). Even using the best available information from botanists and land managers, external threats were demonstrated for only three non-spring species. Browsing and grazing by feral goats and macropods is a suspected threat for many residual species and a targeted assessment of this impact on population dynamics is critical. Domestic grazing is often cited as a threat to threatened species (Hartley and Leigh 1979; James *et al.* 1999; Woinarski and Fisher 2003), however it is only directly implicated in the decline of one species (*Acacia ammophila*) in western Queensland. This mirrors a broader trend, where a number of processes seem to be cited as default 'threats' in many conservation planning documents, with no attempt made to assess or quantify these claims. In addition to grazing, changed fire regimes are assumed to represent a threat to many residual species (Environment Australia and QPWS 1999; NSW NPWS 1999) despite the fact that even after abundant rainfall, groundcover in many habitats remains too low to support fire. The perceived threat of fire is not supported by direct observation that we could record in western Queensland. At present, no listed species outside spring habitats are threatened by exotic species. However, this situation could change rapidly if an invasive exotic species became prevalent in critical habitats.

Species falling into threat syndromes 4 and 5 are so poorly known that no practical management actions are defensible or possible. Forty of the 106 listed and candidate species are known from fewer than five collections in Queensland, and many more are represented by scant recent records. As such, it is very difficult to provide even ball-park estimates of range and population size, let alone assess decline or potential threats. Surveys for these species are obviously required and subsequent ecological studies need to focus on identifying population declines and potential threats (Keith 2000; Fensham and Fairfax 2008). Ten listed species are known to be affected by some degree of temporal rarity (syndrome 4), while preliminary observations suggest that a further 30 trawl species may exhibit sporadic germination and recruitment. This paper has exposed numerous special issues which must be considered for plant conservation in the arid zone. Separating the effects of genuine spatial rarity, temporal rarity and low collection effort, as well as quantifying the nature and extent of threatening processes, will be crucial to achieving conservation outcomes in these areas.

CHAPTER 5.

SPECIALISED AND STRANDED: HABITAT AND BIOGEOGRAPHIC HISTORY DETERMINE THE RARITY OF PLANT SPECIES IN A SEMI-ARID MOUNTAIN RANGE

INTRODUCTION

The association of rare species with restricted habitat types has long been recognized, and confinement to such habitats is the most well-documented and frequently cited cause of plant rarity (Kruckenberg and Rabinowitz 1985; Harrison 1999; Boulangeat *et al.* 2012). Rare species seldom occupy all available habitat, however, leading biologists to search for other factors that may limit their distribution and abundance.

Experimental studies and field observations indicate that many plants are limited by their ability to reach suitable habitat, establish and persist (Eriksson and Jakobsson 1998; Ehrlén *et al.* 2006). Species with limited viable seed production and no adaptations for long-distance dispersal will be more restricted than those with seeds that are dispersed by vertebrates or wind (Van der Veken *et al.* 2007), although even species that produce large quantities of viable seed with adaptations for long-distance dispersal can be seed-limited (Wild and Gagnon 2005). Other species may have low establishment ability even if diaspores reach suitable habitat (Clark *et al.* 2007), or may not persist to form viable populations (Turnbull *et al.* 2000). A distinction between 'propagule-limited' and 'niche-limited' species has been made depending on whether distribution is more strongly influenced by habitat or seed availability (Moore and Elmendorf 2006).

In many cases, however, habitat specificity and species biology are insufficient to explain rarity. Complex factors such as landscape and evolutionary history and the stochastics of local extinction events may be critical (Fiedler and Ahouse 1992; Karst *et al.* 2005; Parmentier *et al.* 2005), particularly in old landscapes where allopatric speciation can occur under conditions of relative stability (Hopper and Gioia 2004). These factors are often difficult to quantify and account for, and typically interact with habitat requirements and species biology to create the observed distribution patterns of species.

Anthropogenic impacts can also influence the distribution and abundance of species. Long histories of traditional management are important for the persistence of species in some landscapes (Frie *et al.* 2012; Eriksson 2013), whereas other species may be advantaged by more recent anthropogenic disturbance (Kirkpatrick 2007). Conversely, many species have become rare due to anthropogenic impacts, particularly over the past two centuries, either via direct removal of individuals (Cardel *et al.* 1997) or via the destruction or modification of habitat (Lavergne *et al.* 2005; Martorell and Peters 2005). In landscapes with a short evolutionary history of grazing, existing theory suggests that grazing-sensitive species will decline in areas subject to consistent grazing pressure and some may persist only in water-remote refugia (Milchunas and Noy-Meir 2002; Landsberg *et al.* 2003).

Mountain ranges, and particularly rock outcrops, are recognized worldwide as centres of endemism for plant species. Various outcrop communities in the western USA have high concentrations of endemic species (Baskin and Baskin 1988), serpentine barrens being the best documented (Harshberger 1903; Harrison *et al.* 2006). Distinctive floras have also been described on mountain ranges and outcrops in Africa (Moustafa and Zaghloul 1996; Burke 2003a), the Middle East (Danin 2008), South America (Alves and Kolbek 1994; Porembski *et al.* 1998) and Australia (Crisp *et al.* 2001; Gibson *et al.* 2012). These habitats provide unique challenges for plants, including shallow or skeletal substrates, high ultraviolet radiation, wind exposure and evapotranspiration, large daily thermal variations and often unusual soil chemistry, but may also have provided refugia in relatively mesic subhabitats during climatic fluctuations. In tropical and temperate regions, rock outcrops are regarded as xeric 'islands' within a humid matrix, although they can provide relatively mesic conditions for plant growth in arid zones (Burke 2003b). Their bioclimatic status in intermediate or semi-arid positions along this global axis, however, remains unclear.

Here, we investigate the causes of rarity in relation to the flora of a semi-arid mountain range containing 19 rare and restricted species (Silcock *et al.* 2011) that has been subject to 150 years of grazing by introduced herbivores (Fensham and Fairfax 2008).

We hypothesize that if rare species are primarily niche-limited, their occurrence will be predictable within specific habitats. If they are limited by intrinsic biology or biogeographical history, their distribution will be less predictable and better explained by biological and/or biogeographical factors. Alternatively, if plants have become rare due to herbivore pressure, they will show a preference for lightly grazed areas away from permanent water points. To test these hypotheses, we characterize the habitats in the study area and calculate the probability of rare plants occurring in each. We then examine the occurrence of rare plants in relation to individual species biology, the distance to water and biogeography.

METHODS

Study area

The Grey Range, together with smaller offshoot ranges, is composed of Tertiary sandstone and stretches 700 km through inland eastern Australia. The northern part of the system was selected for this study, because preliminary surveys showed it to contain a high concentration of rare species (Silcock *et al.* 2011). This is the point where the range is broadest, stretching over 100 km from east to west (Figure 5-1). Referring to the Grey Range as mountains is a little generous, because its elevation falls from 450 m above sea level on tablelands in the north-east to just over 200 m above sea level in the south. The climate is semi-arid, with average annual rainfall decreasing from 485 mm in the north-east to 300 mm in the south-west of the study area. Most rain falls from December to March. Summer temperatures are hot, with maxima throughout December–February averaging 35 °C and regularly exceeding 40 °C, and the short winters are characterized by warm days and cold nights that often fall below 0 °C. Fieldwork from October 2010 to September 2013 was preceded by exceptional rainfall, with one rainfall station (Trinidad) near the centre of the study area receiving 795 mm in 2010 (more than double its average annual rainfall) and 620 mm in 2011, with near-average rainfall in 2012.

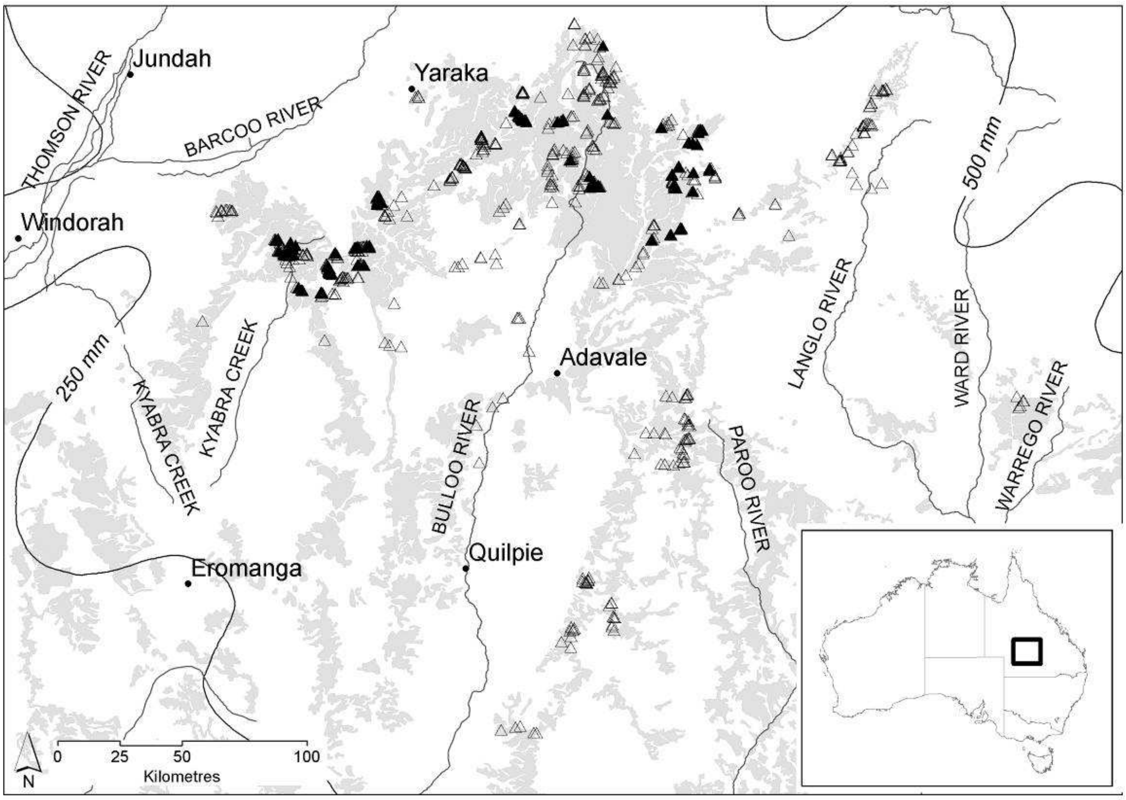


Figure 5-1 Northern Grey Range study area in Queensland, Australia, showing towns, rainfall isohyets (250 and 500 mm per annum), major drainage lines and Grey Range and offshoot Tertiary sandstone ranges (shaded grey). Filled triangles show detailed habitat and grazing-intensity sites; open triangles are rare-plant survey sites.

Feral goats (*Capra hircus*) are patchily common and high numbers of native euros (*Macropus robustus*) occur throughout the area, with domestic cattle (*Bos taurus* and *Bos indicus*) and native grey kangaroos (*Macropus giganteus*) being mostly restricted to the lower slopes and valleys. Grazing both by goats and by macropods is likely to be limited to some extent by water availability (Ealey 1967; Dawson *et al.* 1975; Russell *et al.* 2011), rendering water-remoteness gradients a valid means of studying the effects of grazing on vegetation (Fensham *et al.* 2010a). Fire is rare in the Grey Range due to the naturally sparse ground-cover, although some mulga and shrubby tablelands may burn after exceptional seasons.

Target species

Seven species currently listed under Queensland's *Nature Conservation Act 1992* and one listed on the *Rare or Threatened Australian Plants* (ROTAP) list (Briggs and Leigh 1996) have been recorded from the northern Grey Range, as have 11 species of conservation concern (Silcock *et al.* 2011). Most are long-lived trees and shrubs, with only one annual species included (Table 5-1). Life-history, distribution and abundance data were calculated from survey data, field observations, taxonomic treatments and Queensland Herbarium specimens. Extensive field searches (*c.* 330 hours) informed our total population estimates, calculated as the product of the number of plants found and the proportion of the total suitable habitat within the species' range that was searched (based on vegetation mapping combined with field survey data and, where possible, satellite imagery). Dispersal distance was estimated based on dispersal mechanisms, diaspore size and, where applicable, the range of animals assisting in dispersal. Evidence of recruitment was determined as the presence of seedlings or a range of size classes, including young plants.

Water mapping

Permanent and semi-permanent natural water-bodies (waterholes, springs and rockholes) were mapped through interviews with long-term land managers (Fensham *et al.* 2011c). Artificial waters were identified after comparing available data sources with GOOGLE EARTH imagery (2010) for the study area, and then checking their status with landholders. Land managers also provided an assessment of goat population densities at the time of sampling.

Table 5-1 Geographical data, biological attributes and evidence of grazing impact for rare plant species recorded from the northern Grey Range, Queensland, Australia. Status: V, Vulnerable; N, Near Threatened (under Queensland's *Nature Conservation Act 1992*); 3K, listed in *Rare or Threatened Australian Plants* (geographical range > 100 km but in small populations + poorly-known and suspected of being at risk; Briggs and Leigh 1996). Life-form: T, tree; S, shrub; PF, perennial forb; AF, annual forb.

Species	Family	Status	Life-form	Geographical range (area of occupancy, km^2)	Estimated population size (number of populations)	Dispersal unit (length, mm)*	Dispersal mechanism, distance (m)	Recruitment (% of populations)	Populations grazed (%)
Acacia sp. (Fermoy Road I. V. Newman 487)	Mimosaceae	—	T	46,700 (250)	750,000 (25)	Seed with aril (5)	Ant, 50	22.0	0.0
Acacia sp. (Ambathala C. Sandercoe 624)	Mimosaceae	—	T	1310 (5)	5000 (6)	Seed (3)	Unknown, 50	50.0	0.0
Cadellia pentastylis	Surianaceae	V	T	360,610 (10,000)	500,000 (50)	Winged fruit (300)	Wind, 100	0.0	0.0
Calandrinia sp. (Lumeah R. W. Purdie 2168)	Portulacaceae	—	AF	61,240 (350)	838,718,000 (66)	Seed (1.5)	Wind, 1000	100	0.0
Dodonaea intricata	Sapindaceae	—	S	1160 (13)	92,000 (9)	Winged fruit (13)	Fruit, 500	11.1	0.0
Eremophila stenophylla	Myoporaceae	3K	T	54,830 (150)	41,000 (20)	Drupe (14.5)	Fauna, 5000	24.1	69.0
Euphorbia sarcostemmoides	Euphorbiaceae	V	S	899,300 (200)	440,000 (46)	Berry (5)	Unassisted, 10	8.3	0.0
Goodenia atriplexifolia	Goodeniaceae	—	PF	56,100 (202)	2,520,000 (35)	Winged fruit (2.5)	Wind, 1000	37.1	0.0
Hakea maconochieana	Proteaceae	V	S	16,100 (50)	53,400 (13)	Winged seed (10)	Wind, 500	7.7	0.0
Indigofera oxyrachis	Fabaceae	V	S	8240 (31)	50,000 (9)	Seed (1.5)	Unassisted, 10	14.3	3.6
Kunzea sp. (Forster 35406)	Myrtaceae	—	S	0.01 (0.01)	32 (1)	Seed (0.5)	Wind, 1000	0.0	0.0
Melaleuca kunzeoides	Myrtaceae	V	S	2 (0.02)	200 (2)	Seed (0.5)	Wind, 1000	0.0	0.0
Nyssanthes impervia	Amaranthaceae	—	S	8 (1)	16,250 (2)	Barbed fruit (12)	Fauna, 5000	50.0	50.0
Ptilotus remotiflorus	Amaranthaceae	—	S	161,060 (39)	1,230,000 (45)	Tufted seed (15)	Wind, 500	26.7	4.4

Rhaphidospora bonneyana	Acanthaceae	V	S	32,070 (13)	164,800 (14)	Seed (3)	Short-distance ballistic, 10	26.7	33.3
Ricinocarpos crispatus	Euphorbiaceae	—	S	2440 (20)	429,500 (15)	Fruit segment (6)	Unassisted, 10	36.8	15.8
Sauropus ramosissimus	Phyllanthaceae	—	PF	2,284,160 (20,000)	100,000 (60)	Winged seed (7)	Wind, 1000	36.4	0.0
Sida asterocalyx	Malvaceae	—	S	30,280 (157)	936,000 (24)	Winged fruit (2)	Wind, 1000	0.0	33.3
Xerothamnella parvifolia	Acanthaceae	V	S	287,260 (240)	7,635,700 (65)	Seed (3)	Short-distance ballistic, 10	17.4	84.9

*Diaspores with short-distance ballistic or unassisted dispersal are assumed to have a potential dispersal distance of 10 m, those moved by ants 500 m, those with appendages (wings or hairs) to facilitate wind-dispersal 1000 m, and the two species assisted by larger fauna (*Nyssanthes impervia* by macropods and goats and *Eremophila stenophylla* by cattle, goats and emus) 5000 m.

Site selection and measurement

Preliminary surveys identified seven major vegetation units within the study area (Table 5-2). No habitat-characterization sites were located in sheltered habitats, encompassing gorges and boulder fields, which occur throughout the study area but are extremely variable both within and between sites; 90 such sites were, however, surveyed for rare plants and included in the habitat-probability and grazing analyses. The other habitat types were broadly homogeneous in geomorphology, vegetation structure and floristics. The sampling scheme was designed to capture a representation of each type at a range of distances from water.

Table 5-2. Sites in the northern Grey Range, Queensland, Australia, by habitat and distance to water. Detailed measurements were not taken in sheltered habitats (see Methods).

Habitat unit (typical dominant trees / shrubs)	No. detailed sites by distance to water (km)			Total	Additional survey sites	Total sites
	0–2	2–4	4–6			
Barren plateau (*Acacia stowardii* / *Hakea collina*)	6	7	5	18	128	146
Bendee slope (*Acacia catenulata*)	6	5	5	16	104	120
Bendee tableland (*Acacia catenulate*)	6	4	5	15	57	72
Gidgee toeslope (*Acacia cambagei*)	5	4	4	13	57	70
Mulga tableland (*Acacia aneura*)	4	6	5	15	100	115
Shrubby tableland (*Acacia ramulosa* / *Acacia stowardii*)	3	4	4	11	23	34
Sheltered habitats (gorge / boulder fields)	—	—	—	—	90	90
Total				88	559	647

At each site, the canopy cover of trees (> 2 m tall) and shrubs (< 2 m) was assessed using point intercepts every metre along a 200-m transect. The cover of rocks, pebbles (< 1 cm diameter), logs, litter, biological soil crust and plants was recorded in ten 1 m × 1 m quadrats, spaced evenly along two 50-m lines from the centre of the site. Each species was assigned an abundance score of the number of quadrats in which it was recorded. A 10-minute incidental search of each one-hectare site was also conducted, and any additional species encountered were given an abundance score of one. Nomenclature follows Bostock and Holland (2007); 240 voucher specimens have been deposited at the Queensland Herbarium (BRI).

Dung was counted along two 100 m × 1 m belt transects arranged in a cross formation from the centre of the site. Pellets of yellow-footed rock-wallaby (*Petrogale xanthopus celeris*), euros (*Macropus robustus*), red/grey kangaroos (*Macropus rufus*, *M. giganteus*), goats, cattle, horses, pigs and echidnas were readily distinguishable in the field. Dung was split into 'old' (still intact but dry and bleached) and 'fresh' (black) classes. This method produced a measure of relative grazing pressure at each site (Fensham *et al.* 2010a).

At each site, the presence and abundance of target plant species (Table 5-1) was recorded. Additional survey sites were located in the six habitat types, as well as in sheltered habitats. Population size was estimated through complete census or sub-sampling areas of typical density through quadrats or transects (Keith 2000).

Data analysis

Floristic data (ground layer, shrubs and trees) were ordinated with non-metric multidimensional scaling (NMDS) using the default settings in PRIMER Version 6 (Clarke and Gorley 2006). All other analyses were conducted using R 2.12.0 (R Development Core Team 2010). Soil and vegetation-structure parameters were compared between habitat units by one-way ANOVA using Tukey's tests to compare individual means. Soil-probe, rock and biological-crust data required log-transformation prior to analysis. The distribution of grazing pressure was analysed in relation to distance to water by Spearman rank correlations, considering total dung counts, macropods only, goats only, new dung and old dung, and excluding sites where goats were absent.

The probability of a target species being found in a given habitat was calculated as the proportion of sites surveyed where a species was found. Only points within the geographical range of each species, determined by drawing a convex polygon around all records of the species, were included when calculating habitat probabilities. Spearman correlations were used to examine the presence and abundance of rare species in relation to the distance to water in each habitat. Individual correlations were only possible for the 10 species recorded at more than five sites.

Barren plateaux form ‘islands’ within an *Acacia*-dominated system and can be mapped from satellite (SPOT10) imagery (2008); the distributions of their seven endemic species were used to explore the influence of habitat fragmentation on rarity. The area of each plateau, the distance to its nearest neighbour (measured from the plateau edge) and the area of plateaux within 10 km^2 (calculated from the centroid of each plateau and excluding the focal plateau) were calculated from projected spatial data using SPATIAL ANALYST tools in ARCINFO 10.0 (ESRI, Redlands, CA, USA). Pearson correlations revealed that these two isolation variables were strongly negatively correlated, so only the area of plateau within 10 km was used in the models. There was no significant correlation between plateau size and area of plateaux within 10 km. Binomial generalized linear models were used to test whether the presence of a species was related to the size of the plateau and its isolation from other plateaux. For each species, a model considering interactions between the two explanatory variables (log-transformed) was fitted and compared to a simpler model which included only the main effects for area and isolation, using chi-square analysis. In all cases, the simpler model was not significantly worse and was used for analysis.

RESULTS

Overview and characterization of habitat types

Eighty-eight sites were measured across six habitat units at distances from water ranging from 0.2 to 7.8 km. An additional 559 survey sites were surveyed for rare plant across seven habitats (Table 5-2). Although extremely variable and not measured, sheltered habitats are differentiated from other habitat units by the presence of boulders and vertical cliffs 2–15 m tall, passages, overhangs and scree slopes developed between boulders and at the base of cliffs, and high tree/shrub canopy cover and leaf litter (both often > 70%). They occur along higher escarpments and support vegetation with affinities to dry rain forest, including species which are seldom seen in other habitats and many of which are at the western edge of their range.

All other habitats except barren plateaux are dominated by *Acacia* species (Table 5-2). Gidgee (*Acacia cambagei*) toeslopes had a significantly higher clay fraction and were significantly less acidic than all other units (Table 5-3). Barren plateaux had significantly higher amounts of fine sand and were the most acidic, but this difference was only significant in relation to mulga tablelands. Barren plateaux had shallower soils, and mulga deeper soils, than all other habitat units. With their skeletal soils, exposed rock pavement and extremely low plant cover (Table 5-3), barren plateaux are considered the only rock-outcrop habitat in the study area.

Table 5-3. Mean habitat parameters by habitat type in the northern Grey Range, Queensland, Australia. Standard errors are given in parentheses. Means sharing the same superscript are not significantly different from each other [Tukey's honest significant difference (HSD), $P > 0.05$]. Stars show significance levels: $^{**}P < 0.01$; $^{***}P < 0.001$.

	Barren Plateau	Bendee Slope	Bendee Tableland	Gidgee Toeslope	Mulga Tableland	Shrubby tableland	F	p-value
Soil parameters								
Clay (%)	19.4 $(6.7)^{A}$	22.2 $(4.4)^{A}$	20.9 $(4.8)^{A}$	28.4 $(7.8)^{B}$	21.8 $(3.7)^{A}$	21.7 $(3.3)^{A}$	4.63**	0.001
Silt (%)	15.0 $(3.7)^{AB}$	14.3 $(3.3)^{AB}$	13.8 $(4.2)^{A}$	18.7 $(3.6)^{B}$	19.7 $(5.5)^{BC}$	20.4 $(3.8)^{C}$	7.39***	0.000
Fine sand (%)	36.1 $(4.6)^{A}$	29.0 $(5.8)^{BC}$	27.4 $(4.5)^{BC}$	25.6 $(5.6)^{B}$	31.4 $(5.9)^{AC}$	32.3 $(2.2)^{AC}$	8.89***	0.000
Coarse sand (%)	29.5 $(9.0)^{AB}$	34.6 $(11.7)^{AB}$	37.9 $(9.1)^{A}$	27.3 $(6.8)^{B}$	27.1 $(10.7)^{B}$	25.5 $(5.3)^{B}$	3.89**	0.003
pH	4.9 $(0.3)^{A}$	5.3 $(0.3)^{AB}$	5.1 $(0.5)^{AB}$	6.9 $(0.6)^{C}$	5.4 $(0.4)^{B}$	5.3 $(0.4)^{AB}$	38.73***	0.000
Soil probe (cm)	1.3 $(0.9)^{A}$	2.4 $(1.0)^{B}$	2.8 $(1.7)^{B}$	4.1 $(2.6)^{B}$	9.3 $(5.1)^{C}$	3.5 $(1.5)^{B}$	15.30***	0.000
Physical parameters								
Rocks (%)	77.6 $(15.9)^{A}$	66.7 $(25.9)^{A}$	50.9 $(25.1)^{B}$	54.5 $(26.6)^{AB}$	10.4 $(16.6)^{C}$	39.3 $(24.6)^{B}$	16.93***	0.000
Litter (%)	0.7 $(0.7)^{A}$	23.8 $(16.3)^{BC}$	16.5 $(12.4)^{B}$	17.3 $(7.2)^{BC}$	41.0 $(18.9)^{C}$	15.0 $(14.6)^{B}$	60.97***	0.000
Biological crust (%)	7.1 $(11.8)^{AB}$	1.7 $(6.1)^{A}$	8.9 $(9.8)^{AB}$	1.2 $(2.6)^{A}$	13.4 $(11.9)^{B}$	14.0 $(14.9)^{B}$	3.97**	0.003
Vegetation parameters								
Plant cover (%)	1.6 $(1.8)^{A}$	8.6 $(9.2)^{A}$	7.1 $(10.6)^{A}$	28.9 $(8.6)^{B}$	29.6 $(21.6)^{B}$	28.9 $(15.8)^{B}$	16.11***	0.000
Total groundcover (%)	9.4 $(13.4)^{A}$	34.1 $(18.5)^{B}$	32.6 $(20.3)^{B}$	47.4 $(8.0)^{BC}$	83.9 $(27.9)^{D}$	57.8 $(25.5)^{C}$	29.37***	0.000
Tree cover (%)	1.44 $(1.78)^{A}$	48.28 $(18.62)^{B}$	36.53 $(24.93)^{C}$	23.40 $(12.35)^{D}$	35.78 $(23.65)^{C}$	6.63 $(6.22)^{A}$	35.11***	0.000
Shrub cover (%)	3.6 $(2.0)^{A}$	2.7 $(8.7)^{A}$	1.6 $(2.3)^{A}$	5.0 $(9.5)^{A}$	5.2 $(7.2)^{A}$	25.1 $(17.0)^{B}$	12.60***	0.000
Total species richness	9.9 (4.7)A	12.3 (5.0)A	8.5 (4.2)A	22.0 (5.5)B	19.0 (6.7)B	18.1 (4.6)B	16.23***	0.000

Environmental distinctions between habitat types are confirmed by the ordination of the floristic data. Mulga and shrubby tablelands, and bendee tablelands and bendee slopes occupy distinct areas of the ordination space, albeit with relatively high overlap, whereas gidgee toeslopes and barren plateaux are clearly separated from all other types and from each other (Figure 5-2). Pairwise comparisons showed all units to be significantly different from each other, with bendee slopes and bendee tablelands ($P = 0.010$) and mulga and shrubby tabletops ($P = 0.004$) the most similar (for all other units, $P < 0.001$). Forty clay-soil species occurred only in gidgee toeslopes, and 10 species were restricted to barren plateaux, mostly characteristic shrubs that form sparse, stunted communities. (See Appendix 5-1 for a full list of species and their incidence at sites by habitat.)

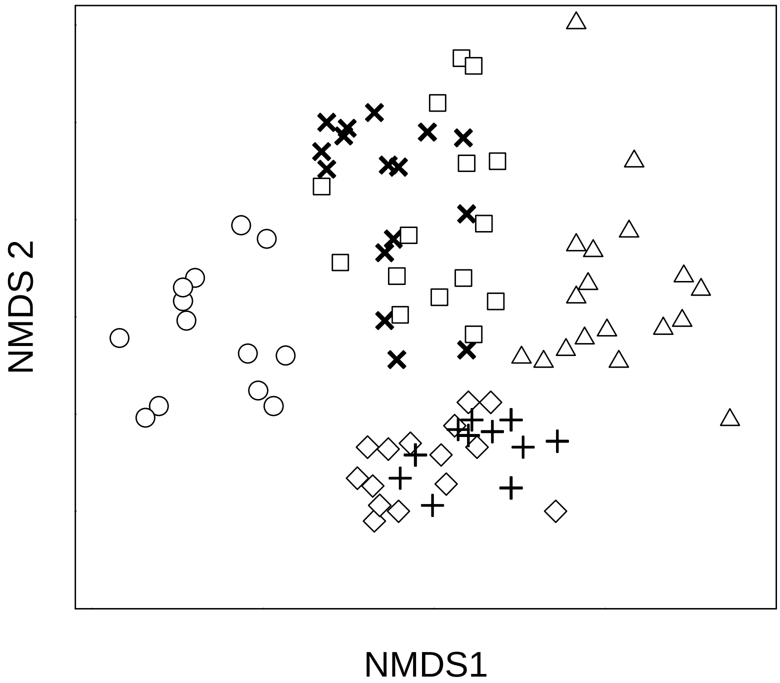


Figure 5-2. Two-dimensional non-metric multidimensional scaling (NMDS) ordination diagram of untransformed floristic abundance data from 88 sites in the Grey Range, Queensland, Australia (Bray-Curtis similarity metric, stress = 0.17). Circles, gidgee toeslope; triangles, barren plateaux; +, shrubby tableland; ×, bendee slope; square, bendee tableland; diamond, mulga tableland.

Occurrence of rare species

Rare plants were concentrated in three restricted habitats: gidgee toeslopes (four species) and barren plateaux (seven species), both of which were clearly separated from other habitat types in soil and vegetation (Figure 5-2, Table 5-3, Figure 5-3b), as well as sheltered habitats (five species) (Figure 5-3a, Table 5-4). There was some overlap between the species found in gidgee toeslope and those found in sheltered habitats, but all barren-plateau species were absent or very rarely found in other habitat types. *Acacia* sp. (Fermoy Road I. V. Newman 487), *Calandrinia* sp. (Lumeah R. W. Purdie 2168), *Euphorbia sarcostemmoides* and *Goodenia atriplexifolia* occasionally occurred in other habitats (Table 5-4), but these were always adjacent to large expanses of barren plateau. Some high probabilities, particularly of *Acacia* sp. (Ambathala C. Sandercoe 624), *Cadellia pentastylis* and *Nyssanthes impervia*, are the result of a species having a very limited range and thus few sites being surveyed within that range. Despite the majority of rare species being mostly restricted to one or more of these three habitat units, most did not occur predictably within their preferred habitat (Table 5-4). Only three species [*Acacia* sp. (Fermoy Road I. V. Newman 487), *Ricinocarpos crispatus* and *Xerothamnella parvifolia*] occurred in at least 50% of sites within their habitat units.

Figure 5-3. Unusual and restricted habitats of the Grey Range, Queensland, Australia: (a) boulder field, showing complex habitat including boulders, passages between them and relatively dense vegetation; (b) barren plateau, showing rock outcropping and very low vegetation cover, but also fissures and cracks that support plant growth.

Table 5-4. Probability (%) of a plant species occurring in a particular habitat within its geographical range, northern Grey Range, Queensland, Australia. Number of sites per habitat searched within each species' geographic range recorded in brackets. Probabilities of greater than 10% are bolded. Only one population each of *Sauropus ramosissimus*, *Kunzea* sp. (Forster 35406) and *Melaleuca kunzeoides* were found in the study area and these are not included.

Species	Barren plateau	Bendee slope	Bendee Tableland	Gidgee Toeslope	Mulga tableland	Shrubby tableland	Gorges/ boulder fields
Acacia sp. (Fermoy Road I.V.Newman 487)	**69.7 (33)**	6.3 (32)	8.8 (25)	-	8.0 (25)	4.0 (25)	2.4 (41)
Acacia sp. (Ambathala C. Sandercoe 624)	-	-	-	-	-	-	**41.7 (12)**
Cadellia pentastylis	-	-	8.3 (20)	-	-	-	**33.3 (6)**
Calandrinia sp. (Lumeah R.W. Purdie 2168)	**44.6 (83)**	1.4 (86)	4.9 (61)	-	2.5 (2)	-	-
Dodonaea intricata	**36.4 (22)**	-	-	-	-	-	-
Eremophila stenophylla	-	-	-	**10.3 (40)**	-	-	-
Euphorbia sarcostemmoides	**18.5 (135)**	-	-	-	2.5 (120)	3.0 (33)	-
Goodenia atriplexifolia	**38.5 (52)**	-	5.0 (20)	-	-	4.0 (25)	-
Hakea maconochieana	**15.0 (80)**	-	-	-	-	-	-
Indigofera oxyrachis	-	-	-	**10.0 (40)**	-	-	2.0 (50)
Nyssanthes impervia	-	-	-	-	-	-	**50.0 (4)**
Ptilotus remotiflorus	-	-	-	**18.2 (55)**	-	-	-
Rhaphidospora bonneyana	-	-	-	7.7 (39)	-	-	**26.8 (41)**
Ricinocarpos crispatus	-	5.0 (20)	-	-	-	-	**61.1 (18)**
Sida asterocalyx	**42.1 (38)**	-	-	-	-	-	-
Xerothamnella parvifolia	-	-	-	**63.2 (57)**	-	-	-

There were no correlations between distribution, abundance and predictability of the 19 target species and dispersal ability. With the exception of the two species with animal-assisted dispersal (*Eremophila stenophylla* and *Nyssanthes impervia*), most species had no capacity for long-distance dispersal (Table 5-1). Recruitment was observed of all species except *Cadellia pentastylis*, *Melaleuca kunzeoides*, *Kunzea* sp. (Forster 35406) and *Sida asterocalyx*, although it appears to be rare for *Euphorbia sarcostemmoides* (recruitment observed in 8.3% of populations), *Dodonaea intricata* (11.1%), *Indigofera oxyrachis* (14.3%) and *Hakea maconochieana* (15.4%).

The sizes of 2246 barren plateaux, totalling 585 km^2, ranged from 0.003 to 17 km^2 (mean ± SD: 0.28 ± 0.7 km^2). One hundred and forty-five (6.5%) plateaux, ranging in size from 0.022 to 17.15 km^2 (0.64 ± 1.7 km^2), were surveyed. The amount of barren plateau habitat within 10 km^2 of the surveyed plateaux ranged from 0.0089 to 29.40 km^2 (4.87 ± 4.46 km^2). Plateau area had a strong positive effect on the occurrence of the seven rare species as a group (P = 0.0001), and every species except *Hakea maconochieana* (P = 0.341) and *Goodenia atriplexifolia* (P = 0.051) was significantly more likely to be found on larger plateaux. Isolation had no significant effect on incidence of individual species, but was marginally significant (P = 0.043) when the species were considered as a group (Table 5-5).

Table 5-5. Generalized linear models of plant species occurrence as a response to plateau area and connectivity (defined as the area of plateau habitat within 10 km²), northern Grey Range, Queensland, Australia. Only plateaux within the range of each species are considered. Significant results are shown in bold.

Species	Number of plateaux (*n* present)	% plateaux present	Plateau area		Connectivity	
			Z	*P*	*Z*	*P*
Acacia sp. (Fermoy Road I. V. Newman 487)	33 (23)	70%	2.689	**0.007****	0.294	0.769
Calandrinia sp. (Lumeah R. W. Purdie)	83 (37)	45%	3.077	**0.002****	−0.645	0.519
Dodonaea intricata	22 (8)	36%	2.486	**0.013***	1.089	0.276
Euphorbia sarcostemmoides	135 (25)	19%	2.746	**0.006****	1.562	0.118
Hakea maconochieana	80 (12)	15%	0.952	0.341	−0.119	0.905
Goodenia atriplexifolia	52 (20)	38%	1.951	0.051	0.176	0.160
Sida asterocalyx	38 (16)	42%	2.411	**0.016***	0.048	0.962
All rare species	139 (55)	40%	3.821	**0.0001*****	2.025	**0.043***

Grazing impacts

Average dung counts across sites ranged from 0 to 25 per square metre and were variable within habitats. Horses and sheep were recorded at one site each, and cattle were present on three gidgee toeslopes and two barren plateaux. Yellow-footed rock wallabies were recorded at 26 sites, and other macropods occurred across all sites. Red and grey kangaroos and wallaroos displayed a preference for gidgee toeslopes and mulga and shrubby tablelands over bendee habitats and barren plateaux, and yellow-footed rock wallabies were most frequent on bendee slopes and shrubby tablelands ($F = 4.86$, $P = 0.01$). Goats were estimated by landholders to be low in number at the time of sampling on all but four properties, and were recorded at 43 sites. Where they did occur, they were most abundant on bendee tablelands, bendee slopes and shrubby tablelands. Five sites, including one more than 6 km from permanent water, were obvious goat camps, with densities up to 200 pellets m^{-2}.

There were no significant correlations between grazing pressure (based on dung counts) and distance to water for any herbivore species or dung age. The occurrence of rare plants was not related to distance from water or dung abundance for any habitat unit. None of the 10 individual species occurring at more than five sites displayed any preference for sites far from water, or for sites with low dung counts. Although five palatable perennial shrubs (*Xerothamnella parvifolia*, *Rhaphidospora bonneyana*, *Eremophila stenophylla*, *Nyssanthes impervia* and *Sida asterocalyx*) were often heavily browsed, they all occurred in abundance at sites close to water and with high dung counts, and substantial recruitment of all except *Sida asterocalyx* was observed. Populations of other species were untouched or rarely browsed (Table 5-1).

DISCUSSION

Influence of habitat specialization

The rare plant species of the Tertiary sandstone ranges of the study area have strong affinities for three unusual and restricted habitats. Although these ranges cover *c.* 20,000 km^2 within the study area, the potential habitat for most rare species is relatively small: a total of 585 km^2 of barren plateau, *c.* 2000 km^2 of gidgee toeslope and less than 100 km^2 of sheltered habitat. Bendee-dominated habitats, mulga and shrubby tablelands occupy most of the area, but harbour few populations of rare species. These habitat types have strong environmental and floristic affinities with widespread vegetation dominated by the same species in other situations (Boyland 1973; Fensham *et al.* 2011b; Appendix 5-1).

Distinctive floras occur in mountain ranges globally because the environment excludes other species, and also because they support substrate specialists (Ware 1990; Wiser *et al.* 1996; Harrison *et al.* 2006). Barren plateaux form rock outcrops within an *Acacia*-dominated matrix, and are clearly divergent from any other habitat in our study region, with shallow, rocky, acidic soils and very low organic matter and vegetation cover (Table 5-3, Fig. 5-3b) and, consequently, high solar radiation, temperature fluctuations and wind exposure and low water retention. Although their overall species richness was low, they were floristically distinct from all other habitat units (Table 5-3, Fig. 5-2) due to the presence of 'barrens specialists'. The adaptations of plants to these habitats may be maladaptive on deeper soils or in more fertile or shaded habitats, possibly accounting for their restricted distribution and endemism to habitat (Walck *et al.* 1999; Poot and Lambers 2003).

Rock outcrops tend to represent insular and unusual habitats within forested landscapes, effectively forming biogeographical islands (Burke 2003b). In relatively mesic areas, a disproportionate number of rare species occur in relatively open, rocky environments which effectively form xeric islands (Porembski and Barthlott 2000; Poot and Lambers 2008). These species have become adapted to this environment through the development of strategies to minimize water loss and allow them to avoid droughts. All seven barren-plateau endemics in the Grey Range show such adaptations, including succulence (*Calandrinia* sp. (Lumeah R. W. Purdie 2168), *Euphorbia sarcostemmoides*), leathery leaves (*Acacia* sp. (Fermoy Road I. V. Newman 487), *Hakea maconochieana*) and deciduousness in response to drought (*Dodonaea intricata*, *Goodenia atriplexifolia* and *Sida asterocalyx*).

Conversely, rock outcrops in drylands often provide more mesic habitats than their surroundings, with microhabitats including deep cracks and crevices that accumulate weathered bedrock, organic matter and water, and run-on areas that harvest the limited rainfall (Burke 2002; Danin 2008). Field observations suggest that Grey Range barren-plateau species make use of these microhabitats. The root systems of *Euphorbia sarcostemmoides* and *Hakea maconochieana* were both traced to fissures in the plateau surface at numerous sites. Rare *Hakea* species from shallow ironstone soils in arid Western Australia invested more in deep roots in a pot experiment than congeners from other habitats, suggesting that shallow-soil endemics have root systems specialized to locate fissures (Poot and Lambers 2008).

Biogeographical history

Evolutionary and environmental history are likely to be important factors explaining the present distributions of long-isolated niche specialists (Fiedler and Ahouse 1992). The association of rare plants with larger plateaux (Table 5-5) points to a relictual origin for these species, which would have had a more continuous distribution before the gradual erosion of Tertiary lateritic profiles left relatively isolated plateaux (Whitehouse 1940). Populations would have been more vulnerable to local extinction events on small plateaux during Pleistocene climatic fluctuations. The general lack of correlation between isolation and the occurrence of rare plant species indicates a paucity of colonization events in recent times, consistent with the limited dispersal capabilities of the seven species (Table 5-1). Most have seeds that are too large for long-distance wind-dispersal and are not adapted for animal-dispersal (Hassall 1977; Cain *et al.* 2000), meaning that if a species is extirpated from a plateau it is unable to recolonize. This pattern of species becoming 'stranded' on rock outcrops has been documented elsewhere in Australia (Gibson *et al.* 2012). Genetic studies could shed more light on the relative period of historical separation between populations (Yates *et al.* 2007).

Recruitment of barren-plateau species is rare even in good seasons, with five of the six perennials showing recruitment in less than 25% of populations (Table 5-1), and no seedlings were observed of any species, except *Acacia* sp. (Fermoy Road I. V. Newman 487) at one site. Establishment limitations due to high seedling mortality have been documented for numerous rock-outcrop and cliff species (Matthes and Larson 2006; Yates *et al.* 2011). This in turn limits population size and renders populations more vulnerable to local extinctions, compounding the role of stochastic processes in these environments.

Six rare species are restricted to gorges and boulder fields, which provide small, sheltered, relatively moist and structurally complex habitats within the expanses of semi-arid woodlands and shrublands. Rare species such as *Cadellia pentastylis*, *Nyssanthes impervia*, *Rhaphidospora bonneyana*, *Xerothamnella parvifolia* and

Ricinocarpos crispatus all have populations or congeneric relatives in higher-rainfall areas and probably represent populations that shrank back to mesic refugia during climatic cycles of the Pleistocene. This has been proposed for species from similar habitats in other parts of inland Australia (Preece *et al.* 2007; Byrne 2008) and around the world (Médail and Diadema 2009; Migliore *et al.* 2013). Gidgee toeslopes also represent relatively narrow bands where run-on water from escarpments ameliorates water stress to some extent.

Detecting grazing impacts

The lack of correlation between dung counts and the distance to water indicates that euros and goats are influenced by other factors and can range freely without permanent water, at least during the wet years coinciding with our study. Water supplies from ephemeral rockholes are extinguished during droughts but form an extensive network in good seasons. The distance from water did not significantly influence densities of red kangaroo in western New South Wales (Montague-Drake and Croft 2004), and the availability of shelter and forage were more important than water in determining the distribution and abundance of red kangaroos in central Australia (Newsome 1965). Owing to behavioural and physiological adaptations, the euro is even less dependent on surface water than the red kangaroo (Ealey 1967). Other factors apart from water also affect goat density, notably their preference for exposed high tablelands, isolated hills and scarp edges, where they can detect predators (Gross *et al.* 2002; Shrader *et al.* 2008), explaining the high dung densities on bendee and shrubby tablelands.

Despite the drought-hardiness of the dominant herbivores in the Grey Range, it is possible that their activity is constrained by water availability during droughts (Friedel *et al.* 2003). If these constraints exist, they are not manifest in population densities or recruitment characteristics for the target species in our study area. None of them appear to be rare due to grazing pressure, although this may not be the case in other parts of Australia where goat densities are much higher (Pople and Froese 2012), and the impacts of goats on vegetation in these areas requires investigation.

CONCLUSIONS

Ranges along the boundary of the present-day Australian arid zone, including the Tertiary sandstone ranges of inland eastern Australia, appear to have acted as refugia during the dry glacial periods of the Pleistocene, resulting in distinctive floras, including endemic species (Gibson *et al.* 2012). Rare species are now concentrated in restricted and unusual habitats, which have become isolated from each other with little possibility of dispersal between them. Larger plateaux are more likely to support populations of rare species due to local extinction events on smaller, more vulnerable plateaux during dry phases of the Pleistocene. Habitat specialization, reproductive biology and biogeographical history are likely to be critical factors that interact to determine the distribution and abundance of species in geologically stable mountain ranges that contain distinctive and geographically isolated habitats.

CHAPTER 6.

LOST IN TIME AND SPACE: RE-ASSESSMENT OF CONSERVATION STATUS AN ARID-ZONE FLORA THROUGH TARGETED FIELD SURVEY

INTRODUCTION

The protection of rare and threatened species is a central concern of conservation biology. The process of formally identifying taxa at greatest risk of extinction involves the publication of threatened species lists. These lists are used in myriad ways, including allocating resources for species recovery, informing reserve selection, constraining proposed developments and reporting on the state of the environment (McIntyre 1992; Possingham *et al.* 2002). Since the first global classification of extinction risk under the World Conservation Union (IUCN) Red List scheme in the 1970s, nations and jurisdictions have pursued independent listing processes while being guided by Red List criteria, which define threat categories based on quantitative thresholds relating to geographic range, population size, rate of decline and extinction risk (IUCN 2001; Mace *et al.* 2008).

Most of the data available to make conservation assessments for plant species comes from herbarium collections interpreted by botanists (Burgman *et al.* 1995). For poorly surveyed regions and groups, this may be the only data available (Ponder *et al.* 2001; Tobler *et al.* 2007; Rivers *et al.* 2011). Herbarium specimens and their labels provide information on locations of species occurrence, collection date and often a short habitat description. Some labels contain notes on abundance and, occasionally, population structure or threats to the population. Collection date and the presence of flowers and/or fruits can be used to infer phenology and basic life history information. Collections can also inform level of threat for a species based on anthropogenic impacts on its habitat (MacDougall *et al.* 1998) and temporal changes in range or abundance (Lister and Climate Change Research Group 2011).

However, the limitations of herbarium data have led some ecologists to question its value for assessing threat and prioritising conservation effort. Herbarium data is qualitative, usually collected unsystematically and rarely contains information on demographics of or threats to populations, which are vital for conservation assessments (Stern and Eriksson 1996; Willis *et al.* 2003; Farnsworth and Ogurcak 2006). Any inference of rarity will be subject to collection bias, based on the characteristics of the plant including size, conspicuousness and frequency of flowering and fruiting, and the locations where collecting effort is concentrated (Pearce and Bytebier 2002; Kadmon *et al.* 2004).

Where assessments are based on limited collections, considerable extrapolation is required and this can result in spurious conservation assessments (Hall 1987; Golding 2004). Species may be listed on the basis of sparse herbarium records which in reality are relatively common and secure, at least at certain times while genuinely rare and threatened species remain undetected, resulting in waste of scarce conservation resources (Keith 1998; Landsberg and Clarkson 2004). Increasingly, species and recovery actions are prioritised using structured frameworks (Partel *et al.* 2005; Joseph *et al.* 2009), while emerging statistical techniques can facilitate inferences about rates of decline and probability of extinction based on sightings and search effort (Solow 2005; Collen *et al.* 2010). However the accuracy of these approaches remains fundamentally dependent upon the collection record and level of expert knowledge.

These limitations will be most severe in vast inaccessible areas where the collection record is sparse and field surveys are challenging, time-consuming and expensive, such as tropical rainforests and deserts. In arid environments, detecting genuine rarity is further confounded by extreme temporal fluctuations in plant abundance in response to harsh and variable climatic conditions (Holmgren *et al.* 2006). Short-lived forbs and geophytes can persist in low numbers or as dormant propagules or rootstock for most of the time but 'boom' infrequently and briefly in response to seasonal conditions or certain cues (Parsons and Browne 1982; Morton *et al.* 2011). Thus their apparent rarity may reflect life history rather than limited range, abundance or declines. In addition, threats to rare plants in desert environments are often diffuse, subtle and poorly understood, and not able to be reliably inferred from herbarium data.

Lack of basic biological data to assess species against the IUCN criteria remains a major impediment to assigning accurate conservation status throughout large areas of the world. This is reflected in the flora of inland Australia, where there is a lack of basic data on distribution, abundance, population dynamics and realistic threat syndromes for the majority of rare species. This paper presents the results of four years of targeted field surveys for 91 species identified as being rare and potentially threatened across a 635 000 km^2 area of western Queensland (Silcock *et al.* 2011). We examine the nature of desert rarity and implications for assigning conservation status, and propose guidelines for conducting rare plant surveys and making robust conservation assessments in arid zones.

METHODS

Study area

The Mulga Lands, Mitchell Grass Downs and Channel Country (here considered to include the Simpson-Strzelecki Dunefields) biogeographic regions (Thackway and Cresswell 1995) in Queensland, Australia, have a combined area of 635 300 km^2 (Figure 6-1), and comprise the north-eastern section of one of the largest desert systems in the world (Byrne *et al.* 2008). The Mulga Lands contain the most extensive tracts of mulga (*Acacia aneura*) shrubland in Queensland. The rivers and floodplains of the Channel Country are bounded by stony plains, shrublands and dunefields. The Mitchell Grass Downs are characterised by open clay soil plains dominated by *Astrebla* species. All three bioregions are intersected by low Tertiary sandstone ranges, while five groups of springs emanating from the Great Artesian Basin occur within the study area (Fensham *et al.* 2004b).

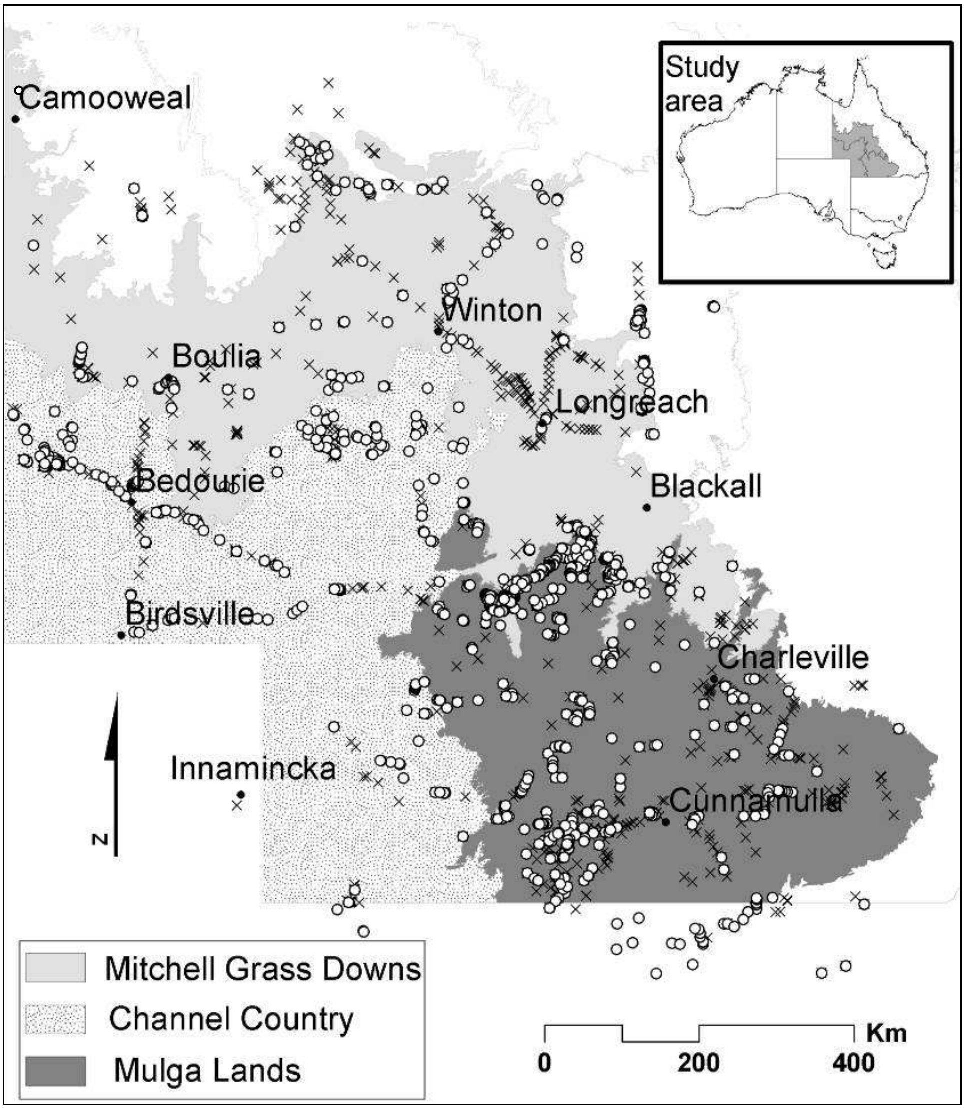


Figure 6-1. Western Queensland study area, showing biogeographic regions, major towns, and targeted search effort (crosses) and candidate species records (filled circles) between 2010 and 2013

Average annual rainfall decreases on a south-westerly gradient from 500 mm along the eastern and north-eastern boundary to 130 mm in the south-west, but is highly variable both within and between years. Summer temperatures are hot with maximums through December-February averaging 35-38°C and regularly exceeding 40°C, while short winters are characterised by cold nights (5-10°C), often falling below zero in the southern half of the area, and warm days averaging 20-27°C. Most of the area is used for extensive cattle and, in the eastern portion, sheep grazing, with relatively small areas occupied by mining leases and conservation reserves. Large macropods are common across the area, with high densities of feral goats in the sandstone ranges and southern Mulga Lands.

Background to threatened species listing

The first list of threatened Australian plants was published by (Specht *et al.* 1974) under the International Biology Program. Following the publication of the IUCN Red Book in 1978, the provisional conservation codes were modified to conform with the IUCN categories and published in *Rare or Threatened Australian Plants* (Leigh *et al.* 1981), most recently revised as (Briggs and Leigh 1996). Threatened species are now listed under the Environmental Protection and Biodiversity Conservation Act (EPBC) 1999 as critically endangered, endangered or vulnerable. Categories and criteria mirror IUCN Red List Version 3.1 (2001) (Table 6-1), but the quantitative thresholds are regarded as guidelines and not strictly applied (Australian Government Department of Environment 2013). In Queensland, species can be listed as endangered, vulnerable or near threatened (formerly rare) under the Nature Conservation Act (NCA) 1992. Assessments in Queensland, in contrast to New South Wales and Victoria, are based on the global range of a species rather than its occurrence within the state. Under both the EPBC and NCA, any person can nominate a species for change of status and it is then assessed by a Threatened Species Technical Committee. Species can be listed as Data Deficient if information is not sufficient to allow confident assessments (Mace *et al.* 2008).

Desktop assessments and data collation

The rarity and threat status of all species occurring in western Queensland was assessed using herbarium data, published information and expert interviews. In addition to currently listed species, those that (i) were known from <10 populations; (ii) had not been collected in study area in the past 20 years; (iii) were likely to be a new or undescribed and restricted species; or (iv) displayed an apparent declining population trend or a suspected threat, were identified as 'candidate species' (Silcock *et al.* 2011).

Table 6-1. Criteria for listing species under Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC) 1999 and Queensland's Nature Conservation Act (NCA) 1992; overall status of a species is determined by the criterion that returns the highest threat category (Source: Australian Government Department of Environment 2013 and Queensland Department of Environment and HeritageProtection 2013, after IUCN 2001)

Criteria	**Critically Endangered (IUCN & EPBC only)**	**Endangered**	**Vulnerable**	**Near Threatened (NCA only)****
A. Reduction in population size*	≥90% / ≥80%	≥70% / ≥50%	≥50% / ≥30%	≥20%
B. Extent of occurrence AND 2/3 of: (a) population structure, (b) continuing declines and (c) fluctuations†	<100km2 + (a) single population	<5000km2 + (a) <5 populations	<20 000km2 + (a) <10 locations	<40 000km2 + at least 10% decline within 10 years or three generations*
B2. Geographic range: area of occupancy + same criteria as for B1†	<10km2	<500km2	<2000km2	<4000km2 + at least 10% decline*
C. Population size + continuing decline	<250 mature individuals	<2500 mature individuals	<10 000 mature individuals	<20 000 mature individuals
D. Population size	<50 mature individuals	<250 mature individuals	**D1.** <1000 mature individuals OR **D2.** very restricted area of occupancy (<20km2) or number of locations (<5)	**D1.** <3000 mature individuals OR **D2.** very restricted area of occupancy (<40km2) or number of locations (<10)
E. Extinction risk (quantitative analysis)	>50% (10 years or 3 generations^)	>20% (20 years or 5 generations^)	>10% within 100 years	>5% within 100 years

* Population size reduction may be 'observed, estimated, inferred or suspected'; time period is 10 years or 3 generations, whichever is longer; threshold depends on the nature of the threat: higher threshold (90, 70, 50%) applicable where the causes of the reduction are clearly reversible AND understood AND ceased; lower threshold (80, 50, 30%) applicable where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible.

** Species can be listed as Data Deficient if information is not sufficient to allow confident assessments.

† Require less than stated extent of occurrence OR area of occupancy AND at least two of three of the following: (a) severely fragmented and known to exist at < x populations (see table for thresholds) (b) Continuing decline (c) Extreme fluctuations in any of the following: (i) extent of occurrence, (ii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations, (v) number of mature individuals; (iii) not relevant for criteria (c) regarding extreme fluctuations. EPBC requires that geographic distribution is 'precarious', which is assessed subjectively on a case-by-case basis. Queensland assessments are based on the global range of a species.

^ Whichever is longer up to 100 years

Field observations, collections and examination of herbarium specimens consigned a further eight species to taxonomic uncertainty. After our surveys, 14 candidate species remain known from <3 records in the study area but are much more common in eastern Queensland or neighbouring states. While populations of these were searched for and recorded, assessments of their conservation status cannot be made without surveys in other regions and they were excluded from this analysis. Notes on the 22 excluded species are provided in Appendix 6-1. Seven restricted and/or rare species were described or ‘discovered’ during our study and were added to the list. Three of these have been described (Bean 2011; Jobson 2013), while four await formal description. The final list comprised 91 species (Appendix 6-2). Nomenclature follows Bostock and Holland (2007).

Field surveys

Targeted surveys for candidate species were conducted over four years between May 2010 and December 2013, with opportunistic surveys in 2007-2009. Surveys encompassed a range of seasons, including the highest rainfall on record for large parts of the study area in 2010 and well above-average rainfall in 2011 and, for the north of the study area, 2009 (Figure 6-2). 2006 and 2008 were dry years across most of the area, with extremely dry conditions returning in 2013. Initial searches were at sites of historical collections, guided by available information on habitat preferences and life history. Herbarium specimens and field guide photos were inspected to gain search images of target species. At each site, habitat data was recorded and search effort quantified in terms of person hours and area searched (McDonald 2004) and preceding seasonal conditions noted. When a species were searched for and not found, this was recorded as a confirmed absence (Marcot and Molina 2007).

When a candidate species was found, total population size was recorded, either through complete census or sub-sampling using transects or quadrats then mapping or estimating population extent. Observations of age structure and apparent grazing impacts or other threats were recorded (Keith 2000). Specimens confirmed identity and >300 were lodged at the Queensland Herbarium. Habitat observations in conjunction with vegetation mapping and high-resolution satellite imagery were used to select sites for further surveys. Targeted searches were supplemented with floristic surveys and collections in poorly-collected areas, as identified through spatial analysis of Queensland Herbarium records.

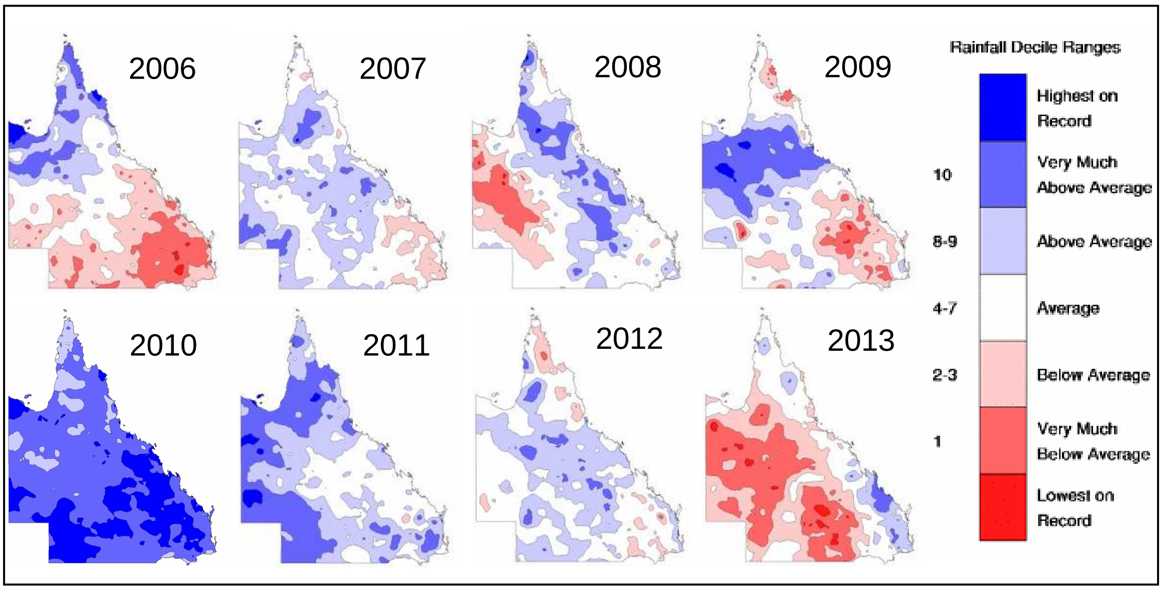


Figure 6-2. Annual rainfall deciles for Queensland for survey period (source: Bureau of Meteorology Climate Data Online, accessed 7 January 2014).

Re-assessment of conservation status

For each species, all records from our surveys and the Australian Virtual Herbarium (www.avh.gov.au) were entered into a Geographic Information System (ArcMap 10.1), erroneous records removed or corrected and extent of occurrence measured as a minimum convex polygon. For some rare species, this measure is prone to dependence on one or two data points, and becomes especially uncertain if all occurrences are not confirmed (Gaston 1994). A conservative approach was taken, with only known extant populations included (i.e. collected within the past 10 years, unless field surveys could not relocate the species at a site). Area of occupancy could be calculated accurately for some species (e.g. spring species), however was mostly estimated as the amount of suitable habitat within a species' extent of occurrence (based on vegetation mapping and field survey data) multiplied by the proportion of sites within suitable habitat where the species was found.

Search effort was calculated for each species by number of sites, person hours and square kilometres searched (calculated as total distance walked or driven * visibility of species at site; where a species was searched for multiple times at one site, subsequent searches were included in hours of search effort but not area searched). Total population estimates were a function of the proportion of total area of suitable habitat searched and the number of plants found:

$$\text{Estimated population} = \frac{\text{Total suitable habitat within range}(km^2)}{\text{Area searched within area of suitable habitat }(km^2)} * \text{Total number of plants found}$$

This equation was only applied where species were known from ≥10 populations. While surveys were used to define range limits and habitat preferences of species, only search effort within their range and suitable habitat (as subsequently defined from survey data) was included in calculations. For Great Artesian Basin (GAB) springs species the dataset of Fensham *et al.* (2004a) was supplemented by additional surveys at all Queensland and New South Wales springs.

Surveys also recorded information relating to habitat requirements, threats (including palatability to herbivores and anthropogenic impacts on habitat), demographic structure, life history and apparent population trends (Keith 2000). For species where we recommend a change of status, Threatened Species Nomination forms (available online at www.ehp.qld.gov.au/wildlife/threatened-species/index.html) were completed and submitted to the Threatened Species Technical Committee. These forms contain details on occurrence, population size, threats and life history, and an example is contained in Appendix 6-3. For candidate species where no change of status is recommended, species profiles were compiled based on survey data, field observations and available literature for future reference; Appendix 6-4 is an example of a typical species profile. All are available on the Queensland Herbarium server.

RESULTS

We conducted 2800 hours of targeted searches for the 91 candidate species. A total of 1970 populations (defined as records separated from one another by more than 10 km and/or a patch of unsuitable habitat) were recorded across the study area and, opportunistically, in neighbouring bioregions in Queensland and adjacent States and Territories (Figure 6-1, Appendix 6-2). Large (>1000 plants), healthy and regenerating populations of 61 of 91 species (67%) of species were found. Species fell into one of seven categories; 3-6 are the 45 species which meet IUCN criteria, while category 7 species require further information (Table 6-2).

Table 6-2. Assessment categories of 91 candidate species based on survey data and application of IUCN criteria

Category	Explanation	Species
1. Species identified by Silcock *et al.* (2011) but assessed as Least Concern after surveys	Herbarium records and expert knowledge suggested species were rare and potentially threatened; surveys revealed them to be abundant and widespread, although extreme fluctuations account for some apparent rarity in 14 species	28
2. Listed species assessed as Least Concern	Currently 2 listed as Endangered, 3 Vulnerable and 8 Near Threatened, but exceed IUCN thresholds based on survey data	13
3. GAB spring species with documented or expected decline	All Endangered (>90% of populations occur in single locality and/or decline is documented) + one Vulnerable	12
4. GAB species without recent or ongoing decline	Vulnerable (D2) due to restricted area of occupancy but no continuing decline documented or expected	7
5. Known threat and decline documented (non-spring species)	5 species grazing-sensitive (heavily grazed and little or no recruitment at >85% of populations) + one threatened by exotic plant invasion; 4 Endangered, 2 Near Threatened under criteria A, B, C and/or D	6
6. Restricted but no threat	2 Endangered (criteria C, <250 mature individuals); 16 Vulnerable and 2 Near Threatened (all D2, area of occupancy <20 km^2 + 2 also D1); includes four 'new' species which have not been intensively surveyed but are extremely restricted	20
7. Data deficient	One population each of 3 species found, 2 surveyed and not found; too little information to make robust conservation assessments, but all potentially eligible for listing	5
		TOTAL=91

Forty-two species (46%) do not meet IUCN criteria for listing. The most common category, accounting for 28 species, was unlisted species identified as candidate species by Silcock *et al.* (2011) which surveys revealed to be extremely common, at least during the good seasons of 2010-11 (Figure 6-2). Half exhibit extreme natural fluctuations which contribute to their apparent rarity. Although most had an area of occupancy below the threshold for listing as vulnerable under criterion B2 (2000 km^2), none exhibit two of the three requisite characteristics and their areas of occupancy and total populations exceed criterion D thresholds (Table 6-1; Appendix 6-2). *Maireana cheelii* is listed as vulnerable nationally but unlisted in Queensland, where it is at the northern edge of its range and not threatened by land clearing and grazing pressure like the southern populations. Thirteen listed species, including two endangered and three vulnerable, are assessed as least concern based on survey data. Half of these are also short-lived species with evidence of temporal rarity, while the others are simply under-collected. Again, nine have areas of occupancy <2000 km^2 but do not meet other criteria for listing.

Fourteen species which meet IUCN criteria for listing are restricted to GAB spring wetlands and five to associated groundwater scalds, accounting for 42% of the 45 species eligible for listing. Eleven qualify as endangered (three critically endangered under the EPBC Act) under criteria B and D and/or A, C and E with a continuing decline documented or likely (Table 6-2; Appendix 6-2). All except *Eriocaulon carsonii* are mostly restricted to a single spring complex, and thus extremely vulnerable to impacts of feral pigs, high total grazing pressure and demographic stochasticity. The three *Eriocaulon* species are selectively dug up by pigs, and *E. aloensis* and *E. giganteum* are restricted to single populations of 2588 and 263 plants respectively (P. Foreman, unpublished data). The decline of the relatively widespread *E. carsonii* has been documented at numerous springs over the past decade. The remaining eight spring species are listed as vulnerable (D2) due to extremely restricted area of occupancy. However there is no evidence of continuing or future decline except for *Calocephalus* sp. (Eulo M.E.Ballingall MEB 2590), which is heavily grazed by goats and/or cattle with limited recruitment at all unfenced populations.

Only six non-springs species are eligible under criteria relating to evidence of continuing decline or probability of extinction (which is required for criteria A, C, E and mostly for 6-2; Table 6-1). *Acacia ammophila* and *A. crombiei* and *Eremophila stenophylla* (all assessed as vulnerable, B2; Appendix 6-2) are long-lived trees or tall shrubs which are heavily grazed by goats and/or cattle with little or no recruitment at ≥85% of populations. The short-lived endangered forb *Ptilotus brachyanthus* was found at just three small highly disjunct populations in 25 hours targeted searching, displays extreme temporal fluctuations and has apparently declined since pastoral settlement. Both *Rhynchharena linearis* and *Sida argentea* are grazing-sensitive and currently known from <10 populations in Queensland despite extensive searching, and are assessed as near threatened (Appendix 6-3).

Twenty non-spring species, including 18 woody perennials and two geophytes, remain sufficiently restricted to warrant listing after extensive surveys despite there being no documented or suspected threat or decline. All are vulnerable (D2), with the exception of *Kunzea* sp. (Forster 35406) and *Calotis suffruticosa*, which are known from single tiny populations and qualify as endangered (C), and *Ptilotus maconochiei* and *Raphidospora bonneyana*, which are listed as near threatened (D2, area of occupancy <40 km^2). *Eremophila tetraptera* exceeds thresholds for listing, however is retained as vulnerable pending demographic surveys. Category 6 includes four ‘new’ species (three ‘discovered’ during surveys and one described in 2012), which have not been intensively surveyed but are highly restricted and meet criteria for listing as vulnerable (D2 and possibly D1).

Five species remain too poorly-known to make robust assessments. One population each of *Vittadinia decora*, *Nymphaea georginae* and *Austrostipa blakei* were found during surveys, while two species (*Spathia neurosa* and *Swainsona similis*) were not found despite 15 and eight hours targeted search effort respectively. Apart from *Vittadinia decora* (listed as near threatened), none are currently listed under state or federal legislation and are recommended for listing as data deficient.

DISCUSSION

Desert rarity and implications for assessing conservation status

Many apparently rare species in vast poorly-collected areas will be found in abundance with targeted surveys. For some species, their apparent rarity is due to being inconspicuous plants in relatively inaccessible habitats (Landsberg and Clarkson 2004). For example, *Xerothamnella parvifolia*, a tangled almost-leafless perennial sub-shrub, was known from 15 collections in Queensland, and just one in the past 10 years, but was found abundantly in footslopes of stony ranges, with >60 populations documented and an estimated total population of 7.6 million mature individuals (Appendix 6-3). For many annual species and geophytes in arid environments, temporal fluctuations in above-ground biomass combine with low collection effort. This was spectacularly demonstrated by *Sclerolaena walkeri*, a short-lived forb which was known from two collections in 1942 and 1964, but dominated large areas of floodplains in south-western Queensland in 2007-2008. Between 2008 and 2013 it was absent or reduced to small patches of dried out almost unrecognisable specimens at most of the 30 sites monitored (J. Silcock, unpublished data). Surveys, especially in wet years, can clarify the status of a relatively large proportion of species previously considered rare and/or threatened.

Species in vast, relatively homogenous arid-zone systems are unlikely to be genuinely rare unless they are restricted to specialised and restricted habitats (Meyer 1986; Yates *et al.* 2011). The main expressions of such habitats in western Queensland are GAB discharge springs and scalds (Fensham *et al.* 2011) and unusual habitats in Tertiary sandstone ranges including barren plateaux, gorges and scree slopes, which together account for 84% of species meeting IUCN criteria. Overall, 86% of all species assessed as vulnerable species are listed under criterion D2. This is the least rigorous criterion and is susceptible to being misapplied (Mace *et al.* 2008), however we consider these species, mostly woody shrubs and trees, are sufficiently restricted to be considered vulnerable under a precautionary approach. No active management is required to ensure their persistence, however monitoring of long-lived perennials every 5-10 years will provide information on population dynamics and detect any threats or declines. Only ten listed species occur in widespread habitats, including two assessed as endangered: *P. brachyanthus* (mixed woodlands on sandy slopes) and *C. suffruticosa* (Mitchell grasslands). Our results suggest that being sparsely distributed across a widespread habitat is an unusual form of rarity (Rabinowitz *et al.* 1986), rather than being overlooked in the listing process (McIntyre 1992; Burgman 2002).

The area covered by most arid zone habitats is so large that only a tiny portion can be surveyed. For example, 30 hours were spent searching 70 sites for *Actinotus paddisonii*, which amounted to $0.5km^2$ searched (0.03% of 1680 km^2 of mapped suitable habitat) because visibility of this tiny forb in hummock grasslands is ≈4 m along any transect walked. Similarly for Mitchell grassland forbs and grasses, between 33 and 150 sites were searched for each species, but with detectability ranging from 4-50 m, 0.2-0.004% of each species' potential habitat was searched. When our survey results are extrapolated using the formula presented in the Methods (e.g. 2800 *Actinotus paddisonii* were found in 0.03% of habitat searched), total population estimates are very large (8.8 million plants in this example; Appendix 6-3). Such estimates are not unreasonable if a species is found relatively predictably in a certain habitat and habitat area can be reliably estimated (Landsberg and Clarkson 2004). For forbs and geophytes such as *Actinotus* these calculations are probably underestimates because the species may be present at a site as dormant seeds or perennial rootstock but not visible at the time surveyed.

Extrapolations and inferences regarding area of occupancy and total population size are unavoidable for species inhabiting vast habitats. It is therefore important to accurately record area searched and number of plants found, and set explicit and conservative rules for calculation of IUCN parameters. Rivers *et al.* (2011) suggest that 15 specimens are required to accurately calculate species range. For population estimates, we suggest that a species must be found at ≥10 sites or have ≥5000 mature individuals before our equation is applied.

Threats and fluctuations

Species which exceed thresholds for listing based on natural rarity (criterion D) can be listed under criteria B or C if they meet at least two of three additional criteria: (i) known from few or severely fragmented populations, (ii) continuing decline, or (iii) extreme fluctuations. Species can also be listed regardless of population parameters if they exhibit recent declines (criterion A) or high probability of extinction (E) (Table 6-1).

Assessing rates of decline in the arid zone is difficult due to the long time scales involved and life history strategies of many plants, which include episodic recruitment and dormant phases (Keith 1998). However, even after extensive surveys, population declines are documented for only six non-spring species. This runs counter to most conservation planning documents which cite grazing by domestic and feral herbivores, altered fire regimes and invasion by exotic species as default threats for most rangeland species (e.g. Hartley and Leigh 1979; Queensland Parks and Wildlife Service 1999; Woinarski and Fisher 2003). There is no evidence that altered fire regimes are a threat to any candidate species in western Queensland, and groundcover in most habitats was too low to support fire even after record-breaking wet seasons (Figure 6-2). *P. brachyanthus* is threatened by exotic plants, with most of its habitat invaded by the introduced pasture grass *Cenchrus ciliaris*, while four perennial species (*A. ammophila*, *A. crombiei*, *E. stenophylla* and *S. argentea*) lack recruitment suggesting declines in most populations under current grazing regimes. A decline is strongly suspected for the perennial vine *R. linearis*, which is grazing sensitive (Parsons 2000) and currently known from four tiny populations in Queensland, despite many hours searching.

The tiny area of occupancy of GAB spring species is mostly natural but compounded by the extinction of many springs since pastoral settlement because of aquifer drawdown (Fairfax and Fensham 2002; Powell *et al.* 2013). While feral pig control and reduction of total grazing pressure will help secure populations of the endangered spring endemics, all remain inherently vulnerable due to demographic stochasticity (Mace *et al.* 2008). Populations of listed species need to be regularly monitoried to more adequately determine population trends.

Under IUCN criteria, geographically restricted or rare species which exhibit extreme temporal fluctuations can be listed if they are known from <10 populations or are severely fragmented, even without evidence of decline (Table 6-1). In reality, fluctuations may be more apparent than real, where the above-ground or detectable abundance of plants changes dramatically but overall population when the seedbank and/or dormant rootstock is considered remains relatively constant. Furthermore, the annual nature of these species confers resilience to grazing as plants complete their lifecycles rapidly in response to favourable conditions (Díaz *et al.* 2007; Silcock and Fensham 2013). Thirty-two candidate species exhibit extreme temporal fluctuations in above-ground dectetability and eight of these are known from <10 populations and/or are severely fragmented (Appendix 6-2). Although technically eligible for listing all are abundant, not declining and do not meet other criteria for listing. We recommend that the temporal fluctuation parameter be applied extremely critically for arid zone plants.

Survey effort in arid zones

While herbarium records provide a good starting point, there is no substitute for surveys to facilitate robust conservation assessments in poorly-collected regions (Keighery *et al.* 2007). Searching for rare plants in such areas is time-consuming and search efficiencies vary widely according to visibility of plants in the field and their period and frequency of growth and/or flowering (Hall 1987). Our results suggest that targeted species-level surveys provide good return for effort where historical collection localities are known to at least 5 km precision. For short-lived species and geophytes, surveys must be responsive to seasonal conditions, and examination of rainfall and flooding conditions preceding previous collections is informative. Once the habitat of a species can be characterised, high-resolution satellite imagery such as GoogleEarth is useful for detecting suitable habitat within extensive unsurveyed areas.

The most difficult species to search for will be those which occur sparsely across vast habitats. While past records can provide a starting point, surveys are likely to be unsuccessful and time-consuming compared to species with easily-definable, specific niches (MacDougall *et al.* 1998). In some cases, a species may be so rare, difficult to detect and/or unknown that intensive field surveys are not justifiable or practical (Marcot and Molina 2007). Our experience suggests that such species are most likely to be found opportunistically, with four of the biggest 'finds' made outside of targeted surveys: the initial sighting of *S. walkeri* and the only large populations of *P. brachyanthus, Indigofera oxyrachis, Sauropus ramossissimus* found in the study area. This also highlights the importance of raising the profile of rare species amongst botanists and land managers in vast, temporally variable systems.

Finding many arid zone species is a matter of 'cracking their code', whether this be getting an eye for fine-scale habitat requirements in a vast landscape (e.g. *Iseilema calvum,* which is restricted to run-on areas and gilgais in Mitchell grassland) or identifying conditions which trigger rare 'boom' events. For numerous western Queensland species, mass germination was triggered by the first substantial rainfall after a sequence of dry years (e.g. *S. walkeri, Ptilotus pseudohelipteroides*; Appendix 6-3). Surveys in poorly-collected areas can also uncover previously unknown or unrecognised taxa (Keighery *et al.* 2007), with these surveys finding at least three previously unknown species, as well as numerous populations of undescribed species previously known from one or two records.

CONCLUSIONS

The method presented here, involving (1) a comprehensive assessment of all taxa occurring in a region to generate a list of candidate species, (2) systematic survey program, and (3) explicit calculations and consistent evaluation against IUCN criteria, can be applied to any poorly-surveyed region. It requires little equipment – access to electronic herbarium records (now widely available with digitisation of collections), GPS, plant press, vehicle and mapping software – and yields basic biological data which is impossible to gather by any other means. This information is vital to assessing conservation status, particularly separating genuine rarity and declines from temporal fluctuations and low collection effort. Our results show that in vast, relatively homogenous areas where habitats have not been substantially modified, few species are likely to be threatened and many are not especially rare, while specialised habitats may harbour unknown and unrecognised species. This work has vastly simplified conservation priorities and actions for western Queensland, with only GAB spring species and six declining species requiring active conservation attention and further surveys recommended for five species. The study of rarity not only enhances regional conservation by honing threatened species priorities, but also has the capacity to enrich our understanding of underlying ecological processes and patterns.

CHAPTER 7.

CONCLUSION

In this final chapter I examine the hypotheses put forward in the Introduction, using the results presented in this thesis and incorporating findings from other studies. I discuss which hypotheses are supported, which are refuted and areas where uncertainty remains, and the implications for conservation and land management in inland eastern Australia. Directions for future research are identified. These conclusions are then considered in the context of recurring debates and narratives of landscape change that have characterised rangeland science and policy globally over the past century.

Testing degradation hypotheses for inland eastern Australia

Table 7-1 summarises the five hypotheses, methods used for testing each as explored in this thesis and a brief outline of my interpretations based on available evidence. Each hypothesis is considered in detail below, with reference to other relevant studies from inland Australia.

Hypothesis 1. There will be clear evidence of landscape change in the historical record, particularly with regard to vegetation structure, landscape processes and relative abundance of native plant and animal species.

Six hypotheses regarding landscape change are considered in detail in Chapter 2, and here I provide a brief summary. The explorer record reveals little evidence of unidirectional vegetation change across inland eastern Australia. Explorers recorded large areas of dense woodland and scrub, particularly gidgee (*Acacia cambagei*), brigalow (*A. harpophylla*) and mulga (*A. aneura*)-dominated communities in the semi-arid zone, and there are no geo-referenced observations of open country now characterised by thick vegetation. Fire was rarely mentioned, with the exception of Aboriginal burning of spinifex-dominated communities, grasslands on the eastern edge of the semi-arid zone and some watercourses. No change in waterhole permanence was evident for most rivers and creeks, although there is tentative support for anecdotal observations of silting in areas of the upper Lake Eyre Basin. Large macropods appear to have increased dramatically in the semi-arid zone, while there are numerous explorer records of medium-sized mammals that are now locally extinct or reduced to fragments within their former range.

Table 7-1. Summary of hypotheses tested in thesis, methods used and brief interpretation of evidence

Hypothesis	Method/s	Interpretation
1. Landscape change in historical record	Explorers	No unidirectional change in vegetation structure or fire regimes; more macropods in semi-arid areas; numerous mammal extinctions.
2. Shifts in plant species abundance +overall declines in diversity	Exclosures; water remote gradients	Little evidence of irreversible degradation at typical levels of grazing in systems studied. Alterations in plant composition range from negligible to moderate, but no overall declines in diversity documented.
3. Lower groundcover and erosion	Explorers; exclosures	Generally little evidence of widespread soil loss and associated silting of waterholes. Substantial soil loss in parts of the Mulga Lands cannot be ruled out, however grazing-induced erosion may be less severe than thought, and perennial grasses remain abundant across large areas following good summer rainfall.
4. Decline of sensitive species	Explorers; exclosures; water remote gradients; rare plant surveys	Very few plant species have declined to the extent that they are rare at a landscape scale, and threats were documented for only six non-spring species. Mammals, particularly those in the critical weight range, have fared catastrophically primarily due to introduced predators. Strong evidence of declines are documented for only two bird species and no reptiles in the study area, although many are poorly known.
5. Invasion by exotics	General landscape observations	Five introduced plant species have widespread impacts on ecological structure and function; others remain confined to small patches or disturbed habitats. Feral predators have had, and continue to have, catastrophic impacts on native mammals.

Some of these findings, particularly regarding the interrelated topics of vegetation structural change and fire regimes, run counter to prevailing paradigms. In particular, Acacia-dominated woodlands and shrublands in the semi-arid zone are generally purported to have thickened since pastoral settlement, primarily due to preferential grazing of grasses, reduced fire frequency and less competition for shrub species (Noble 1997; Beale 2004; Witt 2013). However, the explorer record provides strong evidence that pre-pastoral semi-arid Queensland was a mosaic of open plains, lightly wooded downs, grassy woodlands and dense sometimes impenetrable scrubs, which explorers tried their best to avoid or struggled to forge a path through. Other studies that have employed the historical record systematically also reveal little evidence of unidirectional vegetation change (Denny 1987; Fensham *et al.* 2011a). These findings are supported by the results of (Witt *et al.* 2006; Witt *et al.* 2009), who found only a modest average increase in canopy cover and substantial variation between sites in the central and eastern Mulga Lands since the 1950s, the period when major thickening is purported to have occurred.

This interpretation suggests that the role of fire in shaping vegetation structure in these communities, particularly in 'thinning out' *Acacia* and shrubby species, may also have been overstated. There were no references to fire in mulga communities in three early explorer journals examined (Kennedy and Turner, 1847 and Landsborough, 1862), encompassing >800km travelled through mulga woodlands, including in summer when Aboriginal people were noted firing the spinifex around Charleville and Cunnamulla. This is consistent with data from eastern Australian mulga communities showing that even in long-ungrazed exclosures there is not sufficient biomass to carry fire except following a sequence of above-average rainfall summers (Hodgkinson 2002; Fensham *et al.* 2011b). A review of newspaper articles, historical accounts and interviews with long-term landholders indicates that extensive wildfires tend to occur every 30-50 years, most notably in the 1880s, 1950s, 1970s and 2011-2012. Only high-intensity fires cause substantial death of mature mulga and such fires typically stimulate mass seedling germination of up to 530 000 seedlings per hectare (J. Silcock, unpublished data).

In contrast to *Acacia*-dominated woodlands of the central and eastern Mulga Lands and Mitchell Grass Downs, where the historical record does not indicate unidirectional vegetation change, available evidence points towards a substantial increase in canopy cover in the Mulga Lands of south-western Queensland and adjacent northern New South Wales (Noble 1997; Witt 2013). The dominance of this 'delicate and noxious scrub' over large areas is considered the major manifestation of grazing-induced land degradation (Condon 1986; Mills *et al.* 1989; Daly and Hodgkinson 1996). Unfortunately there are no explorer journals to provide pre-pastoral insights into the original vegetation structure of the western Mulga Lands. However, perceptions of a general thickening trend are supported by post-1950s aerial photography, which shows dramatic increases in shrub cover on rocky and sandy red soils in Queensland's south-western Mulga Lands (Witt and Beeton 1995; Witt *et al.* 2009). This coincided with an overall decrease in grass abundance as inferred from analysis of sheep faeces deposited under the Currawinya shearing shed (Witt *et al.* 1997). However, the drivers of this woody thickening, particularly the relative influence of climate and pastoral management, remain uncertain.

There are few studies quantifying the effect of fire in the Mulga Lands, mostly due to the difficulty of getting a fire to carry in most seasons (Jones and Burrows 1994). Of the major species considered 'woody weeds', *Eremophila mitchellii, E. sturtii* and *E. bowmanii* display high survival rates after fire, *Senna artemisioides* and *Dodonaea viscosa* survival is variable and dependent upon burning conditions, and *E. gilesii* seldom resprouts (Moore and Walker 1972; Wilson and Mulham 1979; Walker *et al.* 1981; Hodgkinson 1998; J. Silcock, unpublished data). Recently-established seedlings of all species are nearly always killed by fire. (Hodgkinson and Harrington 1985) argue that prior to European settlement, widespread shrub establishment events and conditions promoting wildfire were closely coupled, so that during uncommon periods of high rainfall there was widespread germination and establishment of shrubs at the same time as abundant grass growth predisposed the plant community to being burnt, killing most of the seedlings. Thus even though fires were infrequent, occurring perhaps every 25-30 years, they were pivotal in determining ecosystem structure.

Alternatively, Witt *et al.* (2009) hypothesise that woody vegetation cover is especially dynamic in the lower-rainfall western Mulga Lands. An extended dry period in the first half of the 20th century meant that by the 1940s many areas had relatively low woody vegetation cover. With two exceptional 'wets' occurring in the mid-1950s and 1970s, the magnitudes of which were more pronounced in the western Mulga Lands than central and eastern regions, shrubs germinated and grew rapidly with little mortality of the 1950s cohort before the 1970s seedlings became established. This scenario emphasises climate-driven dynamism of woody vegetation over century scales. Death of shrubs and mulga in some areas during dry years in the early to mid-2000s provides some support for this hypothesis. However, this was not sufficient to substantially reduce shrub dominance in most areas (Norman *et al.* 2014; J. Silcock, pers.obs.). The most feasible interpretation supports the principal role of climate in establishment and mortality of shrubs, with grazing impacts and reduced fire frequency perhaps contributing to a general thickening trend.

Increases in shrub density are not necessarily associated with declines in ecosystem function and cannot be universally viewed as a symptom of degradation (Eldridge *et al.* 2011). Recent data from western New South Wales show that there are positive effects of individual shrubs on plant and soil attributes even at levels of shrub encroachment representative of the maximum registered for inland eastern Australia (Soliveres and Eldridge 2014), as well as demonstrating the role of shrub patches as habitat for native fauna (Daryanto and Eldridge 2012) and understorey plants (Howard *et al.* 2012).

The only area where there is clear evidence of substantial change in the explorer record is mammal abundance. While the decline of 'critical weight range' mammals is well documented (Johnson 2006), increases in large macropods in the semi-arid zone are based on anecdotal reports and remain contentious (Auty 2004). The explorer record provides unique pre-pastoral insights, and the ecological impacts of the apparently dramatic increase in wallaroos and grey kangaroos in semi-arid Queensland are discussed below.

Hypothesis 2. Shifts in plant species abundance will be detectable under different management regimes, with palatable and perennial species replaced by unpalatable and annual species in grazed areas, and an overall decline in plant species diversity particularly in low productivity environments.

Data from long-term grazing exclosures reveals little evidence of irreversible degradation at typical levels of grazing in mulga forests, dunefields, floodplains or Mitchell grasslands. The floristic composition of dunefields and floodplains in north-eastern South Australia seem to be largely unaffected by domestic grazing, with no significant differences between grazed and ungrazed treatments in total species richness or abundance, life form richness or abundance, or herbaceous biomass. No species displayed consistent increasing or decreasing trends with grazing. These results suggest that non-equilibrium vegetation dynamics (Ellis and Swift 1988; Briske *et al.* 2003) are prevalent in the annual-dominated systems which characterise the more arid parts of the study area.

Grazing effects were detected in the perennial-dominated mulga and Mitchell grassland exclosures. In the low-productivity mulga forests, hypotheses regarding species diversity and composition (Cingolani *et al.* 2005) were somewhat borne out, with annuals favoured by grazing and highest species richness for most lifeforms in the macropod-grazed treatment, an intermediate grazing disturbance that best approximates the evolutionary history of the environment. Palatable perennial grasses decreased but were not eliminated from grazed areas, and no species were found only in ungrazed treatments. Overall, the findings are not consistent with established assertions that long-grazed mulga has crossed functional thresholds that limit recovery.

In the Mitchell grasslands, livestock grazing altered plant composition but did not cause declines in dominant perennial grasses or overall species richness. Neutral, positive, intermediate and negative responses to grazing were recorded, but no single lifeform group was associated with any response type. Richness and abundance of annual grasses were lower in the ungrazed treatment, perennial herb abundance was significantly higher in macropod-grazed than open-grazed, and annual herb abundance significantly lower in open treatment than other treatments. A long-term seedbank study near Julia Creek in the northern Mitchell Grass Downs found highest species richness in the soil seedbank at the lightest grazing intensity (Orr and Phelps 2013). However, this decline in diversity with continuous grazing does not seem to be a general trend across these grasslands.

Fensham *et al.* (2010a) recorded floristics along grazing gradients in relatively productive swales in the Simpson Desert dunefields and found some grazing-sensitive plant species, but just as many that had benefited from twenty years of cattle grazing. There were almost no trends between grazing intensity and species abundance, richness and diversity at small or large spatial scales, and subtle differences in soil characteristics had a more substantial influence on floristic composition than grazing. In central Australian mulga and chenopod-dominated communities, Landsberg *et al.* (2003) also identified numerous ‘increaser’ and ‘decreaser’ species but found little apparent effect of distance to water on overall species diversity.

Current grazing practices seem consistent with conservation of plant species diversity across most of inland eastern Australia, and results from exclosures and grazing gradient studies do not indicate a wholesale reduction in diversity at regional scales as would be expected with irreversible degradation. While some species, particularly palatable grasses, decreased in mulga and Mitchell grasslands, none were eliminated. It seems that non-equilibrium vegetation dynamics may also prevail in some perennial-dominated systems due to the sporadic nature of rainfall in inland eastern Australia. In good seasons, available forage is sufficiently abundant that stocking rates are rarely high enough to inhibit seed-set of even most palatable species. During extended dry periods these perennial-dominated systems are mostly bare ground, with many shorter-lived grasses dying and persisting in the seedbank (Brown 1986; Grice and Barchia 1992; Orr *et al.* 1993) or the dominant perennials being reduced to twigs or stubble (e.g. *Astrebla* species, *Chenopodium auricomum*). Livestock cannot be sustained and must be removed, ensuring persistence of palatable perennials. The notable exception is mulga communities where the palatable *Acacia aneura* can be pushed to sustain stock through drought, and this is considered a major factor predisposing these communities to degradation (Jones and Burrows 1994; Beeton *et al.* 2005). While this may contribute to the greater floristic differences between grazing treatments relative to the other systems studied, assertions of irreversible degradation are not supported by available data.

Hypothesis 3. The resulting lower groundcover, especially during drought, will lead to accelerated soil erosion, loss of nutrients, scalding and associated silting of creeks and waterbodies.

As discussed under hypothesis one, there is little evidence of silting from the explorer record. While waterholes in localised areas, particularly the upper Lake Eyre Basin, seem to have become shallower, in other regions (e.g. Strzelecki Creek) the explorer record refutes popular assumptions of massive soil loss and associated silting of waterholes in the early years of settlement. This is consistent with negligible grazing impacts found in the dunefields and floodplains of this area (Chapter 3). Fensham *et al.* (2010a) found no perennials that responded negatively to grazing that would seem to have an important role in stabilising soils in the Simpson Desert swales, while in the Mitchell grasslands the dominant *Astrebla* grasses were not significantly reduced by typical levels of grazing (Fensham *et al.* 2014).

It is the Mulga Lands of southern Queensland and northern New South Wales where soil loss is considered to be severe and indicative of widespread degradation. Miles (1993) used concentrations of Caesium-137 in soil profiles to examine soil movement in Queensland's western Mulga Lands. Caesium-137 is not a naturally-occurring isotope so can be used to measure erosion or deposition since atmospheric testing of nuclear weapons began in the mid-1950s (Mabit *et al.* 2008). These results suggest that an average of 20-30 mm of soil have been lost through water and wind erosion, with losses significantly higher from areas of bare ground and those dominated by green turkey bush (*Eremophila gilesii*). Most of this soil was lost from entire 'catchments' rather than being locally deposited on valley floors. It is well-established that loss of topsoil results in loss of nutrients, decreased infiltration and declines in pasture productivity, and these impacts were quantified experimentally by Miles (1993). Combining these results with the visual degradation assessments of Mills *et al.* (1989), Miles (1993) estimated that 30% of the Mulga Lands may be experiencing an 84% decline in plant productivity. If the Mulga Lands have lost as much soil as Miles posits, then degradation has certainly occurred and is likely to be irreversible in severely eroded areas.

There is evidence from the mulga exclosures of decreased perennial groundcover, with yields and thus grass cover significantly higher in ungrazed areas. However, perennial grasses persisted under typical stocking rates for the region at all sites, and much of the mulga country is still dominated by perennial grasses after good summer rainfall, including high densities of palatable 'decreasers' such as *Thyridolepis mitchellii* and *Monachather paradoxa*. Scalded eroded areas and those dominated by *Eremophila gilesii*, which together comprised Miles' 'degraded' categories, often occur in the same paddock as extremely grassy areas, forming a mosaic of apparently degraded and good condition patches which have been subject to identical management history. The Mulga Lands are spatially patchy at a variety of scales (Burrows and Beale 1969; Tongway and Ludwig 1990; Anderson and Hodgkinson 1997), and it seems that at least some of these differences are due to inherent soil or landscape characteristics rather than representing states along a degradation gradient.

Miles' (1993) results provide some support for this interpretation, with electrical conductivity significantly higher in the sub-soil (40-100 mm depth) at his eroded sites (see also Baker *et al.* 1992), suggesting inherent sodicity and susceptibility to water erosion (Rengasany and Olsson 1991; Shaw *et al.* 1994). Areas dominated by *Eremophila gilesii* also display subtle but significant differences in soil characteristics, including lower acid extractable phosphate and slightly higher levels of potassium, which may be at least partly responsible for differences in vegetation. If areas dominated by unpalatable shrubs or devoid of palatable perennial grasses are a natural feature of the landscape at least at certain times, their widespread use as indicators of degradation is fundamentally flawed. Some erosion is natural in the Mulga Lands, which are characterised by large areas of bare ground after extended dry periods even in lightly grazed areas. Grazing can accelerate this process (Greene and Tongway 1989; Greene *et al.* 1994), however quantifying the degree to which this erosion is above the natural background rate is very difficult.

The explorer record sheds light on unvegetated 'scalds', which are often interpreted as signs of degradation where grazing has denuded ground cover and accelerated erosion (Condon *et al.* 1969; Mills *et al.* 1989). Extensive scalded areas along the Barcoo River predate pastoralism. Kennedy passed over 'parched' country 'completely destitute of vegetation' between the Barcoo and Douglas Ponds creek near Blackall (4 August 1847). Further west, he wrote: 'The last 11 miles of this days journey has been over a dead flat or plain…It consists of a white clay blistered and cracked and totally devoid of vegetation' (30 August 1847). Three days later, south of Windorah, he concluded his journal entry: 'This makes the fourth night our horses have been obliged to go without grass for not a blade is visible in any direction' (2 September 1847). Gregory traversed the same area in 1858 and also struggled to find adequate feed for his horses, writing that 'nothing could well be more desolate than the unbounded level of these vast plains, which, destitute of vegetation, extended to the horizon' (23 May 1858). The historical record suggests that scalds in the study area can be expressions of salt in the landscape rather than symptoms of land degradation, while large areas of floodplain have always been completely barren during dry times.

Hypothesis 4. Some plant and animal species will have become rare or disappeared from the landscape.

A small number of plant species are disfavoured by grazing in mulga (Fensham *et al.* 2011b), Mitchell grasslands (Fisher 2001; Fensham *et al.* 2013; Orr and Phelps 2013) and the Simpson Desert (Fensham *et al.* 2010a). The most dramatic decline (>40% reduction in abundance) was documented for the annual grass *Chionachne hubbardiana*. This grass is not generally considered an important component of Mitchell pastures (Phelps and Bosch 2002), but our results indicate that it was probably a major component of grasslands north of the Tropic of Capricorn prior to the introduction of livestock grazing. Most of the other species with negative responses to grazing were perennial grasses (*Monachather paradoxa* and *Thyridolepis mitchelliana* in the mulga, and *Dichanthium sericeum* var. *sericeum*, *Aristida latifolia* and *Panicum decompositum* in the Mitchell grasslands) and perennial vines (*Convolvulus clementii* and *Glycine clandestina* in mulga and *Ipomoea lonchophylla*, which had maximum abundance in macropod-grazed treatment in the Mitchell grasslands). Other studies in Mitchell grasslands also identify 'decreasers', including numerous leguminous species (Orr 1981; Orr and Phelps 2013). In the Simpson Desert, two annual grasses, an annual forb and a perennial shrub displayed decreasing trends and seem to be preferentially grazed. These decreaser species are probably less abundant than in the pre-pastoral landscape. However, all remain widespread and common in the grazed landscape and none have declined so dramatically to be considered rare at a landscape scale.

Grazing gradients in the Simpson Desert and Grey Range revealed no evidence of plants that are so sensitive that the can only survive in water remote areas. In the Simpson Desert, Fensham *et al.* (2010a) found only one species, the widespread annual forb *Swainsona microphylla*, which was restricted to areas of extremely low grazing pressure and it was so infrequently recorded that it could have occurred there by chance. All rare and threatened plant species in the Grey Range showed no association with sites far from water (Chapter 5). These results contrast with other studies which posit that grazing-sensitive species have declined at a regional scale, and some are only able to survive in grazing refuges far from water (James *et al.* 1999; Fisher 2001; Landsberg *et al.* 2003). The major study which presents quantified data to support this theory for the Australian arid zone (Landsberg *et al.* 2002) employs an analysis based on relatively few sampling stations across a broad range of environments. The limited statistical power associated with infrequent species necessitates caution in interpreting responses to grazing, particularly of apparent decreaser species (Fensham and Fairfax 2008). While the association of grazing-sensitive plants with water-remote refuges has not been established for any species, the conclusion of Landsberg *et al.* (2003) that there are more species consistently favoured by water-remoteness than disfavoured appears robust (Fensham and Fairfax 2008).

An alternative approach, then, is to survey for species considered to be potentially rare and/or threatened and assess their viability in the grazed landscape. Targeted surveys (2800 hours) for plant species considered to be rare and/or potentially threatened in western Queensland revealed many to be widespread and abundant at least in good seasons. Their apparent rarity was due to sparse collections across vast and often inaccessible areas combined with temporal rarity for short-lived and geophytic species. Large (>1000 plants), healthy and regenerating populations of 61 of the 91 species (67%) considered to be potentially rare and/or threatened were found (Chapter 6). Although 27 species will remain listed under IUCN criteria by virtue of being naturally restricted, only six non-spring species are threatened or declining. This runs counter to most conservation planning documents which cite grazing by domestic and feral herbivores and altered fire regimes as default threats for most rangeland species (e.g. Hartley and Leigh 1979; Queensland Parks and Wildlife Service 1999; Woinarski and Fisher 2003).

Acacia ammophila and *A. crombiei* and *Eremophila stenophylla* (all assessed as vulnerable, B2) are long-lived trees or tall shrubs which are heavily grazed by goats and/or cattle with little or no recruitment at ≥85% of populations. The short-lived endangered forb *Ptilotus brachyanthus* was found at just three small highly disjunct populations in 25 hours targeted searching, displays extreme temporal fluctuations and most suitable habitat is invaded by the introduced pasture grass Cenchrus ciliaris. Both *Rhynchharena linearis* and *Sida argentea* are grazing-sensitive and currently known from <10 small populations in Queensland despite extensive searching, and are assessed as near threatened. The tiny area of occupancy of Great Artesian Basin spring species is mostly natural but compounded by the extinction of many springs since pastoral settlement (Fairfax and Fensham 2002; Powell *et al.* 2013).

Five species remain too poorly-known to make robust conservation assessments. One population each of *Vittadinia decora*, *Nymphaea georginae* and *Austrostipa blakei* were found during surveys, while two species (*Spathia neurosa* and *Swainsona similis*) were not found despite 15 and eight hours targeted search effort respectively. Apart from *Vittadinia decora* (listed as near threatened), none are currently listed under state or federal legislation and further surveys at appropriate times are required to ascertain their status. Overall, there is no evidence that any plant species have become extinct since pastoral settlement, and only a tiny fraction have declined to the extent that they have become rare at a regional scale.

In stark contrast, extinctions and declines of formerly abundant mammals, particularly ground-dwelling species falling within the Critical Weight Range (35 – 5500g; Johnson and Isaacs 2009), can only be described as catastrophic. Nineteen mammals have disappeared from inland eastern Australia, while a further 12 are listed as either Endangered or Vulnerable and nine as Near Threatened (Woinarksi *et al.* 2014; Appendix 7-1). Flow-on effects of some mammal declines on ecosystem structure and function have been documented, however their full magnitude will remain speculative for many species (Johnson 2006; Noble *et al.* 2007; Eldridge and James 2009).

Birds and reptiles have fared better, with no recorded extinctions from inland eastern Australia. Of the 17 birds (including subspecies) which are listed or considered potentially rare and/or threatened, 14 show no evidence of decline in the study area (Garnett *et al.* 2011), while there is no evidence that any reptiles have declined (Wilson and Swan 2010). However, there are historical declines documented for some unlisted species (Franklin 2000), while many species remain too poorly known to allow confident assessments of their status and their naturally restricted distributions render them vulnerable to impacts from concentrated grazing pressure and wildfires (Appendix 7-1). Many threats implicated in fauna declines such as broadscale vegetation clearing, conversion of grassland to cultivation and destruction of wetlands are occurring in more mesic areas on the fringes and beyond the study area. Altered fire regimes are a major factor implicated in ongoing declines of bird species across northern Australia (Woinarski and Legge 2013), and may also affect birds in spinifex-dominated communities in the study area (M. Tischler, pers.comm.). As for plant species, the endemic fauna of GAB springs, including eight fish, 38 molluscs and numerous invertebrates, have also declined with the destruction of their habitat (Ponder 2003; Fensham *et al.* 2010b).

Mirroring the results of rare plant surveys (Chapter 6), recent fauna surveys in the eastern Mulga Lands (Teresa Eyre, Stephen Peck, pers.comm., June 2014), Mitchell Grass Downs (Alicia Whittington, pers.comm., June 2014), and the Simpson Desert (Dickman 2013) have revealed that some species considered rare or restricted are actually quite common and widespread, at least in certain seasons. Woinarski *et al.* (2014) cite numerous species which recent surveys following good seasons have shown to be more widespread and/or abundant than previously thought, including the Carpentarian antechinus (*Pseudantechinus mimulus*), Julia Creek dunnart (*Sminthopsis douglasi*) and dusky hopping mouse (*Notomys fuscus*) in the study area. The cryptic, irruptive and/or highly nomadic life histories of many arid zone fauna species, the night parrot (*Pezoporus occidentalis*) being the classic example, adds an extra confounding element to the challenge of detecting rarity and threat.

A range of factors are commonly implicated in arid zone fauna declines and extinctions, primarily introduced predators, habitat degradation, inappropriate fire regimes, competition from introduced herbivores and interactions between these factors (Morton 1990b; Reid and Fleming 1991; Dickman *et al.* 1993; Smith *et al.* 1994; Lunney 2001; Woinarski *et al.* 2014). In many cases, particularly where declines were rapid, causes remain poorly understood and debate continues over the relative importance of introduced predators and habitat degradation. The results presented in this thesis, which show that changes to vegetation and fire regimes are less severe than often assumed, support the argument of Johnson (2006) that introduced predators are primarily responsible for mammal declines. Feral cats and/or foxes are directly implicated in the decline of 28 mammal species in the study area, while there is strong correlative evidence of negative impacts of domestic and/or feral herbivores for only four species (Appendix 7-1). The timing of extinctions also supports this hypothesis, with many species disappearing before pastoralism or rabbits had become established in more arid areas, whereas feral cats had colonised all of Australia by the 1890s (Abbott 2002; Woinarski *et al.* 2014).

While the impacts of introduced herbivore grazing may exacerbate predation pressure in some cases (Moseby and Kemper 2008), a more critical role of rabbits was probably in supporting high densities of foxes (Johnson 2006). A growing body of evidence points to a substantial role for dingoes in limiting fox and cat numbers (Johnson *et al.* 2007; Kennedy *et al.* 2012), and their continued persecution in sheep and to a lesser extent cattle rangelands may represent the major impact of pastoralism on the remaining mammal fauna. Expansion of artificial watering points also has the potential to facilitate the incursion of introduced predators into formerly waterless areas (Brandle *et al.* 1999; McRae 2004). Both topics are the subject of ongoing debate and research.

Hypothesis 5. Introduced species of plants and animals will have proliferated, changing ecosystem structure and function.

Although more than 200 exotic flora species have been recorded in the study area (Queensland Herbarium records, accessed July 2014), most are restricted to disturbed areas such as townships, homesteads and roadsides, or have become naturalised as scattered components of native vegetation communities with little ecological impact (e.g. *Sonchus oleraceus*, *Cynodon dactylon*, *Echinochloa colona*, *Verbesina encelioides*, *Argemone ochroleuca*). Only a fraction of these have proliferated to the extent that they substantially impact ecosystem structure and function (Table 7-2).

Buffel grass (*Cenchrus ciliaris*) is the most widespread exotic species in inland eastern Australia, and the one with the clearest ecological impacts. It is somewhat restricted by soil type, forming dense swards on sand ridges in the Mulga Lands and Mitchell Grass Downs, lighter-textured soils within Mitchell grasslands, cleared areas and poplar box remnants in the eastern Mulga Lands, pulled gidgee and brigalow, and along creeklines in a variety of vegetation communities. Data collected following recent wet summers indicate that it continues to expand in some areas (Fensham *et al.* 2013). The biodiversity and ecological impacts of buffel grass are well documented (Franks 2002; Butler and Fairfax 2003; Smyth *et al.* 2009; Miller *et al.* 2010), however it is productive and nutritious fodder for cattle and continues to be promoted by some pastoralists and there is little prospect for control once it has become established (Friedel *et al.* 2011). Other exotic grasses such as lovegrass (*Eragrostis trichophora*) and Indian couch (*Bothriochloa pertusa*) seem to be mostly restricted to roadsides in the study area.

Table 7-2. Major introduced plant species* recorded from the study area, and their distribution and impact

Species	Distribution/habitat	Ecological impacts
Cenchrus ciliaris (buffel grass)	Widespread; forms dense swards on sand ridges in the Mulga Lands and Mitchell Grass Downs, lighter-textured soils within Mitchell grasslands, cleared areas and poplar box remnants in the eastern Mulga Lands, pulled gidgee and brigalow, and along creeks in a variety of vegetation communities	Reduced diversity of native species (Franks 2002; Jackson 2005); increased intensity and frequency of fires (Butler and Fairfax 2003; Miller *et al.* 2010)
Acacia nilotica (prickly acacia)	Northern Mitchell Grass Downs; densest infestations in Winton-Hughenden-Julia Creek triangle	Conversion of grassland into thorny shrubland and loss of groundcover (Parsons and Cuthbertson 2001; Grice 2004, 2006); also potential impacts on grassland fauna (Lundie-Jenkins and Payne 2000)
Prosopis spp. (mesquite complex, includes *P. pallida, P. glandulosa, P. velutina*)	Scattered throughout area, mostly isolated trees around bores and yards, with denser infestations in northern Mitchell Grass Downs and on Bulloo River (the latter seems to be contained)	
Parkinsonia aculeata (parkinsonia)	Rivers, creeks, swamps and floodplains throughout the area, except for far south-west	Can form dense stands in formerly open areas
Cryptostegia grandiflora (rubber vine)	Mostly restricted to the northern study area, particularly the Gulf-flowing Rivers and the upper Thomson and tributaries, with occasional records elsewhere; very dense on northern springs of Barcaldine supergroup	Smothers native plants and forms dense thickets (Parsons and Cuthbertson 2001; Grice 2004)
Xanthium occidentale (noogoora burr)	Widespread along drainage lines and floodplains throughout the study area	Can form dense swards, excluding native species (Parsons and Cuthbertson 2001)
Eragrostis trichophora (lovegrass)	Mostly restricted to road edges, where it forms dense but narrow swards; seems to be expanding with increased slashing and disturbance of roadsides	Forms monocultural swards with few native species persisting
Urochloa mutica (para grass)	Isolated occurrences in GAB springs and bore-drains	Scattered/localised in study area, so no widespread environmental impacts in study area.
Ziziphus mauritiana (Chinee apple)	Scattered through northern Mitchell Grass Downs and North West Highlands	
Parthenium hysterophorus (parthenium)	Mostly restricted to roadsides and disturbed areas in south-east of region, with scattered records elsewhere (mostly roadsides and disturbed areas)	
Tamarix aphylla (athel pine)	Mostly confined to planted specimens around homesteads, yards etc, but situation on Finke River south of Alice Springs shows it can form infestations on floodplains	
Cylindropuntia & *Opuntia* spp. (cactus)	>14 species in complex; mostly scattered infestations	
Jatropha gossypiifolia (bellyache bush)	Infestation in Muttaburra area + in North West Highlands	
Bryophyllum delagoense (mother-of-millions)	Isolated infestations known on creeks in eastern Mulga Lands and south-eastern Mitchell Grass Downs	

* Numerous other weeds occur in the study area but are restricted to roadsides and other disturbed areas, e.g. *Melinus repens, Bothrichloa pertusa*. Some are considered serious environmental weeds in higher rainfall climates, but have not spread beyond highly disturbed areas in the study area.

The biggest impact of pastoralism in Mitchell grasslands is probably the spread of the woody leguminous trees prickly acacia (*Acacia nilotica*) and, to a lesser extent, mesquite (*Prosopis* spp.), which have transformed over 60 000 km2 of grassland into thorny scrubland (Osmond 20003; Spies and March 2004). Cattle ingest the pods of both species and are a vector for seed dispersal (Brown and Carter 1998; Brown and Archer 1999). Prickly acacia infestations are densest in the triangle bounded by Hughenden, Julia Creek and Winton in the north-eastern Mitchell Grass Downs (Figure 6-1), while mesquite currently occurs mostly as isolated trees around watering points and yards throughout the study area, with discrete dense infestations in the northern Mitchell grassland and, prior to control, on the Bulloo River floodplain. Numerous wetland weeds occur on rivers, floodplains, springs and boredrains, the most widespread being parkinsonia (*Parkinsonia aculeata*), Noogoora burr (*Xanthium occidentale*) and rubber vine (*Cryptostegia grandiflora*). Other weeds in the study area tend to occur as scattered infestations (Table 7-2). Fortuitously, the harsh and variable climate, particularly in more arid parts of the study area, seems to limit the spread of numerous exotic species which have become problematic in higher-rainfall areas, although this does not negate the need for continued vigilance.

As discussed above, introduced cats and foxes are the major cause of mammal declines, represent the greatest ongoing threat to surviving threatened fauna and appear to be responsible for the striking disparity between dramatic fauna declines and the persistence of the arid zone flora of inland eastern Australia since European settlement. Introduced herbivores occur patchily across the area. Rabbits were historically in plague proportions throughout large areas south of the Tropic of Capricorn and had severe impacts on native species, particularly perennial grasses and shrubs (Foran *et al.* 1985; Lange and Graham 1985). Their decline since the introduction of myxomatosis and calici virus in the 1950s and 1990s respectively has allowed regeneration of many perennial shrubs and trees (Sandell and Start 1999), however they continue to inhibit recruitment of some species (Denham and Auld 2004; Cook and McPhee 2007).

Feral camels roam the Simpson-Strzelecki dunefields and heavily browse preferred woody species (David Albrecht, pers.comm.), although there is little quantified data on their impacts (Edwards 2010). Goats occur patchily across the study area (Pople and Froese 2012), and can have a severe effect on perennial vegetation where they are in high densities (Parkes *et al.* 1996). However, the nature and severity of these impacts are not well documented (Edwards *et al.* 2004; Hacker and Alemseged 2014). Pigs are concentrated around wetlands and their foraging and rooting can have substantial local impacts (Hone 1995; Choquenot *et al.* 1996). Exotic and translocated aquatic species, particularly gambusia (*Gambusia holbrookii*) and redclaw crayfish (*Cherax quadricarinatus*) in the Lake Eyre Basin and carp (*Cyprinus carpio*) and goldfish (*Carassius auratus auratus*) in the Murray Darling Basins, pose a major threat to the biological integrity of inland waterways (Haynes *et al.* 2009; Kerezsy 2010), and to the survival of native fish in Great Artesian Basin springs (Kerezsy and Fensham 2013).

Assessment of degradation, conservation priorities and further research

Overall, there is little evidence for irreversible degradation of the soils and vegetation of inland eastern Australia, and the results presented here generally suggest less ecological change than prevailing paradigms. This is not to say that there are no examples of overgrazing, accelerated erosion, species declines and weed invasion. Heavily grazed areas close to water points have certainly borne the brunt of grazing pressure with associated biotic and abiotic effects (Andrew and Lange 1986a, b; Williams *et al.* 2008; Eldridge *et al.* 2011). Even relatively resilient communities such as Mitchell grassland can be severely impacted by consistently high stocking rates (Hall and Lee 1980; Orr and Phelps 2013), while differences in species composition due to grazing will be detectable in many areas. However, climate fluctuations and subtle soil differences often have greater effects on floristic composition than grazing, and the conservation of plant biodiversity is largely compatible with commercial pastoralism across most of the study area. The main unequivocal examples of degradation are the loss of a suite of medium-sized mammals, extinction of GAB springs and their dependent organisms through aquifer drawdown, and invasion of prickly shrubs and buffel grass which have altered ecosystem structure and function across large areas.

This makes priorities for conservation relatively straightforward. Conservation of the remaining GAB springs and their endemic species is a priority. The Great Artesian Basin Sustainability Initiative (GABSI) bore capping program has made considerable progress but large flowing bores remain very close to some high-value springs, particularly in the Eulo district, highlighting the urgent imperative to rehabilitate bores that may be critical for the preservation of the remaining springs (Silcock *et al.* 2014). Other strategies are site-specific and include fencing, feral animal control, tenured protection agreements at priority springs and, in extreme cases, translocations of threatened species (Kerezsy and Fensham 2013). Populations of listed plant species should be regularly monitored, encompassing accurate population counts and area of occupancy estimates, to assess population trends. There is an ongoing responsibility to ensure that demands for groundwater, particularly for coal seam gas extraction, do not cause further degradation to this already debilitated ecosystem. Priority locations and actions will be further refined through the completion of the Queensland springs database (Rod Fensham, pers. comm.).

Grazing sensitive species form a small but important component of the inland eastern Australian flora and will benefit from the creation of large water-remote reserves where the impacts of domestic and feral livestock are minimised. Distances of at least seven kilometres are required to achieve meaningful relief from grazing, and such refuges must identify and enhance existing water-remote areas (Fensham and Fairfax 2008). Monitoring and continued surveys are required for the six genuinely rare and threatened plant species identified in Chapter 6, as well as the five species which remain data deficient. Further investigation of heavily browsed species and populations with limited recruitment is also required, encompassing numerous shrubs in stony hills and some trees and shrubs in the low dunefields of the southern Queensland and northern New South Wales Mulga Lands (J. Silcock and S. McIntyre, unpublished data).

Control of foxes and cats is critical to the survival of vulnerable mammals such as the bilby and Julia Creek dunnart. This control needs to be flexible and responsive to infrequent irruptions of long-haired rats and subsequent spikes in cat numbers following exceptional rainfall events (Woinarski *et al.* 2014; Peter McRae, pers.comm.).Targeted rabbit control, particularly warren ripping in identified drought refuge areas, holds substantial potential for reducing their populations and damage to vegetation (Edwards *et al.* 2002; Berman *et al.* 2011). Numerous reptile and bird species remain extremely poorly known (Appendix 7-1) and surveys are needed to assess their population trends and conservation status.

Weed control will remain a priority. While there is little prospect for control of buffel grass, prickly acacia is currently being targeted by Desert Channels Queensland, aiming for eradication from less dense areas, containment down river systems and progressive control of heavily-infested areas. This work demonstrates the expense and challenges involved in controlling weeds once they have infested large areas. Numerous weeds in the study area currently occur as scattered plants or small populations that can be controlled cost-effectively (Firn *et al.* 2013), notably isolated rubber vine populations in farm dams and creeks, mesquite in the Channel Country and Mitchell grasslands, and isolated cactus infestations. Intensive control of weeds on GAB springs is also a priority, particularly control of rubber vine and prickly acacia.

There are some areas where the magnitude and effects of landscape change remain uncertain. Most of these relate to the Mulga Lands of Queensland and New South Wales, particularly with regard to the long-term dynamics of the 'delicate and noxious scrub' (Noble 1997) and the extent of historical soil degradation and loss. It is unlikely that there will ever be unequivocal answers to these questions. However, studies on the impacts of fire in these communities and the dynamics of perennial grass species under different grazing regimes will provide further clues. The relative role of soil differences and management in determining vegetation composition and structure, for example turkey bush vs grassy areas, could be tested through detailed soil profile characterisation, while the degradation surveys of Mills (1986) and Mills *et al.* (1989) could be revisited. Numerous sources of historical literature have not yet been systematically collated and analysed (e.g. Dowling 1863; Watson 1882; Struver 1890; Benbow 1901; McManus 1916; Anon. 1963; Anon 1969; Hardy 1969; Ellis 1981; Dunk 2010). Property diaries, Land Commissioner reports and survey plans are also untapped sources of historical information (e.g. Oxley 1987a, b).

Globally, there is evidence of grazing impacts on more productive patches in a generally low productivity matrix (Illius and O'Connor 1999; Elhag and Walker 2010). In the study area, floodplains and dune swales, two productive habitats within generally infertile landscapes, seem resilient to grazing impacts due to the dominance of annual lifeforms (Phelps *et al.* 2007; Fensham *et al.* 2010a; Silcock and Fensham 2011). Productive areas dominated by perennial species may be most vulnerable to degradation. Exclosures on Idalia National Park demonstrate severe impacts of high macropod densities on narrow valleys between stony ranges, with perennial grasses and palatable forbs greatly reduced in abundance (R. Fensham and J. Silcock, unpublished data). Other exclosures in a variety of timbered semi-arid vegetation types, including on Currawinya and Mariala National Parks and Mitchell grassland adjacent to gidgee woodlands near Longreach, also indicate substantial impacts of macropod grazing.

Finally, the ecological implications of the massive increase in goat numbers over the past 20 years in the Mulga Lands (Pople and Froesche 2012; Khairo *et al.* 2013) are completely unexplored. In some areas, the density of goats is now higher than sheep and cattle (Landsberg and Stol 1996), driven by increases in both domestic and feral goats. The line between the two is increasingly blurred as graziers harvest and maintain ‘rangeland’ or ‘semi-feral’ goats at densities where harvesting is profitable (Forsyth *et al.* 2009; Pople and Froesche 2012). Goats are highly selective but adaptable herbivores, preferring grass and herbage in abundant seasons but able to survive on browse, including relatively unpalatable shrubs, bark, leaf litter, roots and fungi in dry times (Downing 1986; Hacker and Alemseged 2014). This allows them to persist much longer than sheep and kangaroos, increasing the potential for overgrazing and degradation. Goats can eliminate preferred perennial shrubs from an area, while severe effects on the herbage layer and groundcover have also been recorded (Wilson *et al.* 1976; Harrington 1986; Russell *et al.* 2011), although Tiver and Andrew (1997) found little impact of goats on regeneration of woody species in eastern South Australia. There is a clear need to better understand the impacts of goats and macropods on botanical composition and vegetation dynamics.

Critical re-assessment of degradation narratives

The results presented in this thesis provide little empirical support for some prevailing narratives of ecological change, and generally support the notion of inland eastern Australia as a healthy rangeland system where grazing and conservation are mostly compatible. The life histories of plant species and the inherent climatic limitations have allowed much of the flora to remain unscathed by the massive upheavals initiated by pastoral settlement. After 150 years, we can clearly identify what we have lost, what continues to decline, and the directions for management and research to address these issues.

However, these results point to a wider problem with identifying arid land degradation. Assumptions of detrimental change due to abrupt management upheavals are compounded by the 'degraded' appearance of many rangelands for much of the time. Landscape narratives can quickly become entrenched across vast regions with no unequivocal reference or 'natural' state. In inland eastern Australia, this is best illustrated by debates surrounding woody vegetation dynamics. There is almost universal consensus among the grazing community that the Mulga Lands are degraded through vegetation thickening (Witt 2013). The importance of fire became entrenched in folklore early in pastoral settlement. For example, pastoralist J.T. Quinn told the 1901 NSW Royal Commission that the West Bogan country was open forest and 'remained like that until 1874, when it became stocked, and the bush fires, *that previously every summer swept through it* and kept down the scrub and undergrowth, became less frequent, and the scrub then grew to an enormous extent' (cited in Hogdkinson and Harrington, 1985:65, my emphasis). In reality, fires would only be able to 'sweep through' this country following exceptional seasons perhaps once every 30-50 years, a fact which rather reduces their importance in narratives of landscape change. Early scientific articles cited only such anecdotal sources but these articles are then cited by others as authoritative evidence of change (Witt *et al.* 2006). Many recent studies typically begin with a statement categorising mulga country as highly degraded (e.g. Beeton *et al.* 2005; Boyland 2006), further perpetuating this paradigm.

One explanation for the disjunct between empirical evidence and popular perception is that people take their early memories, or handed-down memories, as a reference or baseline state. By the 1940s woody vegetation across the Mulga Lands was probably sparse following an extended dry period through the first half of the 20th century, reflected in concerns expressed about the decline and long-term survival of mulga (Beadle 1948; Condon 1949). The wet seasons of the 1950s and 1970s resulted in increases in canopy cover from this drought-depleted state (Witt *et al.* 2009). Wildfires swept through large areas of mulga and shrublands in south-western Queensland in the summers of 2011 and 2012 with mass mortality of mulga and some shrub species (J. Silcock, unpublished data). Substantial mortality of mulga and shrub species during extended dry periods has also been documented (Condon 1949; Cunningham and Walker 1973; Brown 1985; Fensham *et al.* 2012). Available evidence points to these dynamics as being part of a century-scale cycle rather than unidirectional. Many cited instances and rates of thickening are based on measurements of previously cleared or thinned mulga (Burrows 1973a; Beale 2004), which may account for some perceptions of dramatic thickening. *Eremophila gilesii* certainly responds to disturbance and many areas where it is dominant have been previously cleared or thinned (Burrows 1973b; Baker *et al.* 1992).

Fundamentally, the term ‘degradation’ is value-laden, referring to a change of state which is judged to be negative relative to subjectively-chosen criteria, usually grounded in utilitarian considerations. Changes resulting in reduced pastoral productivity, such as perceived woody encroachment and decreases in groundcover, will be perceived as detrimental. However, some of the most disastrous changes from a biodiversity perspective, particularly conversion of native woodlands and pastures to monocultures of introduced perennial grass, are rarely couched in terms of ‘degradation’. Conversely, areas characterised by an abundance of ‘woody weeds’ and/or ‘undesirable’ native pasture species are routinely considered degraded, but in reality may harbour increased diversity of plant and animal species and show no deterioration in functional and structural indicators of landscape health (Good *et al.* 2012; Eldridge *et al.* 2011). In the study area, the perceived negative effects of woody thickening and shrub encroachment have been strongly influenced by the prevalence of pastoralism and the production bias of most research on the topic. However undesirable states for pastoralism do not necessarily equate to ecological degradation.

Ecological histories of rangeland areas will be as diverse as the rangelands themselves, and any global narratives will invariably involve simplifications and generalisations (Barker 2002). Multidisciplinary regional studies combining historical sources, measurement of sites with different management histories and targeted surveys for sensitive and rare elements of the flora and fauna can allow critical assessments of ecological change in regions subject to abrupt management upheavals. In particular, focusing on the fate and trends individual species identified as potentially rare and threatened holds substantial potential as both an unambiguous assessment of degradation and a means of prioritising conservation effort. The methods described in this thesis are broadly transferable across rangelands characterised by similar issues and debates.

It seems the very characteristics long thought to render drylands fragile and susceptible, especially the prevalence of drought and dust, dominance of annuals and extended periods of low groundcover, may actually confer resilience. The perception of drought as a stress on plants, animals and country is a hallmark of degradation narratives. Drought-affected land is often described as ‘suffering…damaged, wrong, corrupted by lack of rain’ (Arthur 2001:43). In reality a climate characterised by long dry spells punctuated by unpredictable ‘boom’ events, and the associated adaptations of the flora, have conferred extraordinary resilience in the face of massive management upheavals so recently imposed upon this ancient land. We should reframe our thinking to view arid lands as resilient but unpredictable, as dependent on extended drought as on the much-lauded booms. Not usually considered an ecological sage, maybe Slim Dusty had it right when he sang an ode to drought. Perhaps it really does ‘take one hell of an old man drought to bring this country back’.

List of References

Aagesen, D. (2000) Crisis and conservation at the end of the world: sheep ranching in Argentine Patagonia. *Environmental Conservation* **27**, 208-15.

Abbott, I. (2002) Origin and spread of the cat, *Felis catus*, on mainland Australia, with a discussion of the magnitude of its early impact on native fauna. *Wildlife Research* **29**, 51-74.

Adam, P. (2000) Rarity, rare plant species and the New South Wales Threatened Species Conservation Act – conservation opportunities and challenges. *Cunninghamia* **7**, 651-669.

Addison, J., Friedel, M., Brown, C., Davies, J. & Waldron, S. (2012) A critical review of degradation assumptions applied to Mongolia's Gobi Desert. *Rangeland Journal* **32**, 125-37.

Allan, G.E. & Southgate, R.I. (2002) Fire regimes in spinifex landscapes, in: Bradstock, R.A., Williams, J.E., Gill, M.A. (Eds.), *Flammable Australia: the fire regimes and biodiversity of a continent*. Cambridge University Press, Cambridge, pp. 145-176.

Allen, G.H. (1949) *Notes on the plants of south western Queensland*. Bureau of Investigation of Land and Water Resources, Brisbane.

Alves, R.J.V. & Kolbek, J. (1994) Plant species endemism in savanna vegetation on table mountains (Campo Rupestre) in Brazil. *Vegetatio*, **113**, 79–86.

Anderson V. J. & Hodgkinson K. C. (1997) Grass-mediated capture of resource flows and the maintenance of banded mulga in a semi-arid woodland. *Australian Journal of Botany* **45**, 331-42.

Anderson, V.J., Hodgkinson, K.C. & Grice, A.C. (1996) The influence of recent grazing pressure and landscape position on grass recruitment in a semi-arid woodland of eastern Australia. *The Rangeland Journal* **18**, 3-9.

Andrew M. H. & Lange R. T. (1986a) Development of a new piosphere in arid chenopod shrubland grazed by sheep. 1. Changes to the soil surface. *Australian Journal of Ecology* **11**, 395-409.

Andrew M. H. & Lange R. T. (1986b) Development of a new piosphere in arid chenopod shrubland grazed by sheep. 2. Changes to the vegetation. *Australian Journal of Ecology* **11**, 411-24.

Anon. (1963) *A history of Milo and Ambathala*. Milo Pastoral Company Limited, Adelaide.

Anon. (1969) Report to the Inter-departmental Committee on Scrub and Timber Regrowth in the Cobar-Byrock district and other areas of the Western Division of New South Wales. Goverment Printer, Sydney.

Archer, S. (1989) Have southern Texas savannas been converted to woodlands in recent history? *The American Naturalist* **134**, 545-561.

Arriaga F. J., Lowery B. & Mays M. D. (2006) A fast method for determining soil particle size distribution using a laser instrument. *Soil Science* **171**, 663-74.

Arrowsmith, J. (1849) Map of Captain Sturt's route from Adelaide into the centre of Australia, constructed from his original protractions, and other official documents, Cartographic material. Held by National Library of Australia, call no. MAP NK2456 / 2157. J. Arrowsmith, Soho Square, London.

Arthur J. M. (2003) *The Default Country: a lexical cartography of twentieth-century Australia*. University of New South Wales Press Ltd, Sydney.

Asner G. P., Archer S., Hughes R. F., Ansley R. J. & Wessman C. A. (2003) Net changes in regional woody vegetation cover and carbon storage in Texas Drylands, 1937-1999. *Global Change Biology* **9**, 316-35.

Asner G. P., Elmore A. J., Olander L. P., Martin R. E. & Harris A. T. (2004) Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources* **29**, 261-99.

Australin Government Department of Environment (2013). Threatened species under the Environment Protection and Biodiversity Conservation (EPBC) Act. Available online at http://www.environment.gov.au/topics/biodiversity/threatened-species-ecological-communities/threatened-species.

Auty, J. (2004) Red plague grey plague: the kangaroo myths and legends. *Australian Mammology* **26**, 33-36.

Ayyad, M.A. (2003) Case studies in the conservation of biodiversity: degradation and threats. *Journal of Arid Environments* **54**, 165-182.

Baamrane M.A.A., Znari, M., Loggers, C., El Mercht, S. & Naimi, M. (2013) Demographic decline of the last surviving Moroccan dorcas gazelles *Gazella dorcas massaesyla* in M'Sabih Talaa Reserve, Morocco. *Oryx* **47**, 578-83.

Baker, D.E., Miles, R.L. & Eldershaw, V.J. (1992) Vegetation cover classes and soil nutrient status of the mulga lands of south-western Queensland. *The Rangeland Journal* **14**, 40-48.

Bakker, E.S., Ritchie, M.E., Olff, H., Milchunas, D.G. & Knops, J.M.H. (2006) Herbivore impact on grassland plant diversity depends on habitat productivity and herbivore size. *Ecology Letters* **9**, 780-8.

Bandler, H. (1995) Water resources exploitation in Australian prehistory environment. *The Environmentalist* **15**, 97-107.

Barker, G. (2002) A tale of two deserts: contrasting desertification histories on Rome's desert frontiers. *World Archaeology* **33**, 488-507.

Barker, R.D. & Caughley, G. (1993) Distribution and abundance of kangaroos (Marsupialia: Macropodidae) at the time of European contact: South Australia. *Australian Mammalogy* **17**, 73-83.

Barker, S. & Lange, R.T. (1969) Effects of moderate sheep stocking on plant populations of a black oak-bluebush association. *Australian Journal of Botany* **17**, 527-37.

Bartoleme, J.W., Fehmi, J.S., Jackson, R.D. & Allen-Diaz, B. (2004) Response of a native perennial grass stand to disturbance in California's coast range grassland. *Restoration Ecology* **12**, 279-289.

Basedow, H. (1919) Herbert Basedow's diaries of the first medical relief expedition amongst the Aborigines of southern Australia. Mitchell Library, Sydney.

Baskin, J.M. & Baskin, C.C. (1988) Endemism in rock outcrop plant communities of unglaciated eastern United States: an evaluation of the roles of the edaphic, genetic and light factors. *Journal of Biogeography*, **15**, 829–840.

Batanouny, K. A. (2001) Plants in the deserts of the Middle East. In: *Adaptations of Desert Organisms* (Ed J. L. Cloudsley-Thompson). Springer-Verlag, Berlin.

Bawden, C. R. (1989) *The Modern History of Mongolia*. Kegan Paul Inernational, London.

Beadle, N.C.W. (1948) *The vegetation and soils of western New South Wales with special reference to soil erosion*. Government Printer, Sydney.

Beale, E. (ed.) (1983) *Kennedy: the Barcoo and beyond – the journals of Edmund Besley Court Kennedy and Alfred Allaston Turner with new information on Kennedy's life*. Blubber Head Press, Hobart.

Beale, I. (2004) Tree and shrub thickening in the Murweh Shire. Report to the Productivity Commission, http://www.pc.gov.au/data/assets/pdf_file/0008/49373/murweh3.pdf [accessed 16 April 2011].

Bean, A.R. (2011) New and reinstated species of the *Solanum ellipticum* R.Br. (Solanaceae) species group. *Austrobaileya* **8**, 412-430.

Beaumont, P. (1993) *Drylands: Environmental Management and Development*. Routledge, London.

Beeton, R.J.S., Page, M.J., Slaughter, G. & Greenfield, R. (2005) Study of Fodder Harvesting in Mulga Regional Ecosystems. University of Queensland, Gatton.

Bell, D.T. (1999) The process of germination in Australian species. *Australian Journal of Botany* **47**, 475-517.

Bell, P., Iwanicki, I., 2002. Historical background, in: Leader-Elliot, L., Iwanicki, I. (Eds.), *Heritage of the Birdsville and Strzelecki Tracks*. Department for Environment and Heritage, South Australia.

Benbow, C.A. (1901) Interior land changes. *Agricultural Gazette of New South Wales* **12**, 1249–54.

Benson, J.S. & Redpath, P.A. (1997) The nature of pre-european vegetation in south eastern Australia: a critique of Ryan, D.G., Ryan, J.R. and Starr, B.J. (1995) The Australian landscape – observations of explorers and early settlers. *Cunninghamia* **5**, 285-328.

Berman, D., Brennan, M. & Elsworth, P. (2011) How can warren destruction by ripping control European wild rabbit (*Oryctolagus cuniculus*) on large properties in the Australian arid zone? *Wildlife Research* **38**, 77-88.

Bestelmeyer, B. T., Duniway, M.C., James, D.K., Burkett, L.M. & Havstad, K.M. (2013) A test of critical thresholds and their indicators in a desertification-prone ecosystem: more resilience than we thought. *Ecology Letters* **16**, 339-45.

Binns, T. (1990) Is desertification a myth? *Geography* **75**, 106-13.

Blackburn, T.M. & Gaston, K.J. (1997) Who is rare? Artefacts and complexities of rarity determination. In *The Biology of Rarity: causes and consequences of rare-common differences*. (Eds W.E. Kunin, K.J. Gaston), pp. 48-60. Chapman and Hall, London.

Blumler, M.A. (1993) Successional pattern and landscape sensitivity in the Mediterranean and Near East. In: *Landscape Sensitivity* (Eds D.S.G. Thomas, R.J. Allison), pp. 287–305. Wiley, Chichester.

Blumler, M.A. (1998) Biogeography of land-use impacts in the Near East. In: *Nature's Geography: New Lessons for Conservation in Developing Countries* (eds K. Zimmerer & K. Young. University of Wisconsin Press, Madison.

BoRong, P., LingKe, Y. (1995) Comprehensive evaluation of rare and endangered plant species in the arid desert zones of China. *Chinese Journal of Arid Land Research* **8**, 141-148.

Bostock, P.D. (2009) BRIMapper, version 3.2.15. Queensland Herbarium: Brisbane.

Bostock, P.D. & Holland, A.E. (eds) (2007) *Census of the Queensland flora 2007*. Queensland Herbarium, Environmental Protection Agency, Brisbane.

Bouche, P., Douglas-Hamilton, I., Wittemyer, G., Nianogo, A., Doucet, J.-L., Lejeune, P. & Vermeulen, C. (2011) Will elephants soon disappear from West African savannahs? *PLoS One* **6**, 1-11.

Boulangeat, I., Lavergne, S., Van Es, J., Garraud, L. & Thuiller, W. (2012) Niche breadth, rarity and ecological characteristics within a regional flora spanning large environmental gradients. *Journal of Biogeography*, **39**, 204–214.

Bowman, D.M.J.S. (2001) Future eating and country keeping: what role has environmental history in the management of biodiversity? *Journal of Biogeography* **28**, 549-564.

Bowman, D.M.J.S. & Brown, M.J. (1986) Bushfires in Tasmania: a botanical approach to anthropological questions. *Archaeology in Oceania* **21**, 166-171.

Box, G.E.P., Jenkins, G.M. & Reinsel, G.C. (1994) *Time Series Analysis: Forecasting and control, 3rd edition*. Holden-Day, San Francisco.

Boyland, D.E. (1973) Vegetation of the Mulga lands with special reference to south-western Queensland. *Tropical Grasslands*, **7**, 35–42.

Boyland, D.E. (2006) Sustainable harvesting of mulga for fodder in the Mulga Lands. Report for AgForce and Department of Natural Resrouces Mines & Water, Brisbane.

Braithwaite, R.W. (1991) Aboriginal fire regimes of monsoonal Australia in the 19th century. *Search* **22**, 247-249.

Branch, L.C., Hierro, J.L. & Villarreal, D. (1999) Patterns of plant species diversity following local extinction of the plains vizcacha in semi-arid scrub. *Journal of Arid Environments* **41**, 173-82.

Brandle, R., Moseby, K.E. & Adams, M. (1999) The distribution, habitat requirements and conservation status of the plains rat, *Pseudomys australis* (Rodentia : Muridae). *Wildlife Research* **26**, 463-77.

Breckle, S.-W., Wucherer, W., Dimeyeva, L.A. & Ogar, N.P. (2012) *Aralkum – a man-made desert: the desiccated floor of the Aral Sea (Central Asia)*. Springer-Verlag, Berlin.

Breman, H. & Dewit, C.T. (1983) Rangeland productivity and exploitation in the sahel. *Science* **221**, 1341-7.

Briggs, J.D. & Leigh, J.H. (1996) *Rare or Threatened Australian Plants (4th edition).* CSIRO Publishing, Canberra.

Briske, D.D., Fuhlendorf, S.D. & Smeins, F.E. (2003) Vegetation dynamics on rangelands: a critique of the current paradigms. *Journal of Applied Ecology* **40**, 601-14.

Brito, J. C., Godinho, R., Martinez-Freiria, F., Pleguezuelos, J. M., Rebelo, H., Santos, X., Vale, C. G., Velo-Anton, G., Boratynski, Z., Carvalho, S. B., Ferreira, S., Goncalves, D. V., Silva, T. L., Tarroso, P., Campos, J. C., Leite, J. V., Nogueira, J., Alvares, F., Sillero, N., Sow, A. S., Fahd, S., Crochet, P. A. & Carranza, S. (2014) Unravelling biodiversity, evolution and threats to conservation in the Sahara-Sahel. *Biological Reviews* **89**, 215-31.

Broennimann, O., Vittoz, P., Moser, D, & Guisan, A. (2003) Rarity types among plant species with high conservation priority in Switzerland. *Botanica Helvetica* **115**, 95-108.

Brooks, K.J., Setterfield, S.A. & Douglas, M.M. (2010) Exotic grass invasions: applying a conceptual framework to the dynamics of degradation and restoration in Australia's tropical savannas. *Restoration Ecology* **18**, 188-97.

Brooks, N. & Legrand, M. (2000) Dust variability over northern Africa and rainfall in the Sahel. In: *Linking Land Surface Change to Climate Change* (Eds S.J. McLaren & D. Kniverton), pp. 1–25, Kluwer Academic Publishers, Boston.

Brown, J.R. & Archer, S. (1999) Shrub invasion of grassland: recruitment is continous and not regulated by herbaceous biomass or density. *Ecology* **80**, 2385-96.

Brown, J. R. & Carter, J. (1998) Spatial and temporal patterns of exotic shrub invasion in an Australian tropical grassland. *Landscape Ecology.* **13**, 93-102.

Brown, R.F. (1985) The growth and survival of young mulga (*Acacia aneura* F.Muell) trees under different levels of grazing. *Australian Rangeland Journal* **7**, 143-8.

Brown, R.F. (1986) The effects of burning, fertilizing, and clipping on populations of *Aristida armata*, *Thyridolepis mitchelliana* and *Monachather paradoxa* in a mulga woodland pasture. *Australian Rangeland Journal* **8**, 4-10.

Browning, D.M. & Archer S.R. (2011) Protection from livestock fails to deter shrub proliferation in a desert landscape with a history of heavy grazing. *Ecological Applications* **21**, 1629-42.

Bureau of Meterology 2012, Climate data online, Australian Government, http://www.bom.gov.au/climate/data/ [accessed 20 January 2014].

Burgman, M.A. (2002) Are listed threatened plant species actually at risk? *Australian Journal of Botany* **50**, 1-13.

Burgman, M.A., Grimson, R.C. & Ferson, S. (1995) Inferring threat from scientific collections. *Conservation Biology* **9**, 923-928.

Burgman, M.A., Keith, D., Hopper, S.D., Widyatmoko, D. & Drill, C. (2007) Threat syndromes and conservation of the Australian flora. *Biological Conservation* **134**, 73-82.

Burke, A. (2002) Properties of soil pockets on arid Nama Karoo inselbergs – the effect of geology and derived landforms. *Journal of Arid Environments* **50**, 219–234.

Burke, A. (2003a) How special are Etendeka mesas? Flora and elevation gradients in an arid landscape in north-west Namibia. *Journal of Arid Environments*, **55**, 747–764.

Burke, A. (2003b) Inselbergs in a changing world – global trends. *Diversity and Distributions*, **9**, 375–383.

Burrows, W.H. (1973a) Regeneration and spatial patterns of *Acacia aneura* in south west Queensland. *Tropical Grasslands* **7**, 57-68.

Burrows, W. H. (1973b) Studies in the dynamics and control of woody weeds in semi-ardi Queensland I. Eremophila gilesii. *Queensland Journal of agricultural and Animal Sicences.* **30**, 57-64.

Burrows, W.H. (2002) Seeing the wood(land) for the trees – an individual perspective of Queensland woodland studies (1965-2002). *Tropical Grasslands* **36**, 202-217.

Burrows, W.H. & Beale, I.F. (1969) Structure and association in the Mulga (*Acacia aneura*) lands of south-western Queensland. *Australian Journal of Botany* **17**, 539-52.

Butchart, S. (2003) Using the IUCN Red List criteria to assess species with declining populations. *Conservation Biology* **17**, 1200-1201.

Butler, D.W. & Fairfax, R.J. (2003) Buffel grass and fire in a gidgee and brigalow woodland: A case study from central Queensland. *Ecological Management and Restoration* **4**, 120-4.

Byrne, M. (2008) Evidence for multiple refugia at different time scales during Pleistocene climatic oscillations in southern Australia inferred from phylogeography. *Quaternary Science Reviews*, **27**, 2576–2585.

Byrne, M., Yeates, D.K., Joseph, L., Kearney, M., Bowler, J., Williams, M.A.J., Cooper, S., Donnellan, S.C., Keogh, J.S., Leys, R., Melville, J., Murphy, D.J., Porch. N, & Wyrwoll, K-H. (2008) Birth of a biome: insights into the assembly and maintenance of the Australian arid zone biota. *Molecular Ecology* **17**, 4398-4417.

Cain, M.L., Milligan, B.G. & Strand, A.E. (2000) Long-distance seed dispersal in plant populations. *American Journal of Botany*, **87**, 1217–1227.

Calaby, J.H. & Grigg, G.C. (1989) Changes in macropodoid communities and populations in the past 200 years, and the future. In Grigg, G., Jarman, P., Hume, I. (Eds.), *Kangaroos, Wallabies and Rat-Kangaroos*. Surrey Beatty & Sons Pty Limited, Sydney, pp. 813-820.

Capon, S.J. & Brock, M.A. (2006) Flooding, soil seed bank dynamics and vegetation resilience of a hydrologically variable desert floodplain. *Freshwater Biology* **51**, 206-223.

Cardel, Y., Rico-Gray, V., García-Franco, J.G. & Thien, L.B. (1997) Ecological status of *Beaucarnea gracilis*, an endemic species of the semiarid Tehuacán Valley, México. *Conservation Biology*, **11**, 367–374.

Cardillo, M., Mace, G.M., Jones K.E., Bielby, J., Bininda-Emonds, O.R.P., Sechrest, W., Orme, C.D.L. & Purvis, A. (2005) Multiple causes of high extinction risk in large mammal species. *Science* **309**, 1239-41.

Caughley, G. (1986) Rangelands, livestock and wildlife, the ecological equivalent of sulphur, saltpetre and charcoal. In: *Rangelands: a resource under siege* (eds P.J. Joss, P.W. Lynch & O.B. Williams). Australian Academy of Science, Canberra.

Chambers, J. (2010) *The Vintage and the Gleaning*. Text Publishing, Melbourne.

Chatty, D. (2001) Pastoral tribes in the Middle East and wildlife conservation schemes: the endangered species? *Nomadic Peoples* **5**, 104-22.

Chillo, V. & Ojeda, R.A. (2012) Mammal functional diversity loss under human-induced disturbances in arid lands. *Journal of Arid Environments* **87**, 95-102.

Choquenot, D., McIlroy, J. & Korn, T. (1996) Managing Vertebrate Pests: Feral Pigs. Bureau of Resource Sciences, Canberra.

Cingolani, A.M., Cabido, M.R., Renison, D. & Solis V.N. (2003) Combined effects of environment and grazing on vegetation structure in Argentine granite grasslands. *Journal of Vegetation Science* **14**, 223-32.

Cingolani, A.M., Noy-Meir, I. & Díaz, S. (2005) Grazing effects on rangeland diversity: a synthesis of contemporary models. *Ecological Applications* **15**, 757-73.

Ciofolo, I. (1995) West-Africa last giraffes: the conflict between development and conservation. *Journal of Tropical Ecology* **11**, 577-88.

Clancy, T.F. & Close, R.L. (1997) The Queensland rock wallabies: an overview of their conservation status, threats and management. *Australian Mammalogy* **19**, 169-174.

Clark, C.J., Poulsen, J.R., Levey, D.J. & Osenberg, C.W. (2007) Are plant populations seed limited? A critique and meta-analysis of seed addition experiments. *American Naturalist*, **170**, 128–142.

Clarke, P.J., Latz, P.K. & Albrecht, D.E. (2005) Long-term changes in semi-arid vegetation: invasion of an exotic perennial grass has larger effects than rainfall variability. *Journal of Vegetation Science* **16**, 237-48.

Clarke, K.R. & Gorley, R.N. (2006) PRIMER v.6: User Manual/Tutorial. PRIMER-E, Plymouth.

Coates, D.J. & Atkins, K.A. (2001) Priority setting and the conservation of Western Australia's diverse and highly endemic flora. *Biological Conservation* **97**, 251-63.

Coates, D.J. & Dixon, K.W. (2007) Current perspectives in plant conservation biology. *Australian Journal of Botany* **55**, 187-193.

Collen, B., Purvis, A. & Mace, G.M. (2010) When is a species really extinct? Testing extinction inference from a sighting record to inform conservation assessment. *Diversity and Distributions* **16**, 755-764.

Colloff, M.J. & Baldwin, D.S. (2010) Resilience of floodplain ecosystems in a semi-arid environment. *The Rangeland Journal* **32**, 305-14.

Condon, R.W. (1949) Mulga death in the west Darling country. *Journal of the Soil Conservation Service of New South Wales* **5**, 7-14.

Condon, R.W. (1986) Scrub invasion on semi-arid grazing lands in western New South Wales - causes and effects. In: *Rangelands: a resource under siege* (eds P.J. Joss, P.W. Lynch & O.B. Williams). Australian Acacdemy of Science, Canberra.

Connell, J.H. & Sousa, W.P. (1983) On the evidence needed to judge ecological stability or persistence. *American Naturalist* **121**, 789-824.

Cooke, B.D. & McPhee, S. (2007) Rabbits and Native Plant Biodiversity. A report complied for Australian Wool Innovation and Meat and Livestock Australia as part of the Invasive Animals Co-operative Research Centre Project 7.T. 6 - Biodiversity Impact of Rabbits. Online at http://www.feral.org.au/tag/rabbits/ [accessed 13 July 2014].

Crawley, M.J. (1987) Benevolent herbivores. *Trends in Ecology and Evolution* **2**, 167-8.

Crisp, M.D., Laffan, S., Linder, H.P. & Monro, A. (2001) Endemism in the Australian flora. *Journal of Biogeography* **28**,183-198.

Croft, M., Goldney, D. & Cardale, S. (1997) Forest and woodland cover in the central western region of New South Wales prior to European settlement. In: *Conservation Outside Nature Reserves* (eds P. Hale and D. Lamb), pp. 394-426. Centre for Conservation Biology, University of Queensland, St Lucia.

Crowley, G.M. & Garnett, S.T. (1998) Vegetation change in the grasslands and grassy woodlands of central Cape York Peninsula. *Pacific Conservation Biology* **4**, 132-148.

Crowley, G.M. & Garnett, S.T. (2000) Changing fire management in the pastoral lands of Cape York Peninsula of northeast Ausrtralia, 1623 to 1996. *Australian Geographical Studies* **38**, 10-26.

Cunningham, G.M. & Walker, P.J. (1973) Growth and survival of mulga (Acacia aneura F. Muell. ex. Benth) in western New South Wales. *Tropical Grasslands* **7**, 69-77.

Cunningham, G.M, Mulham, W.E., Milthorpe, P.L. & Leigh, J.H. (1992) *Plants of western New South Wales, 2nd edn*. Inkata Press, Melbourne.

Dahlberg, A.C. (2000a) Interpretations of environmental change and diversity: a critical approach to indications of degradation - the case of Kalakamate, northeast Botswana. *Land Degradation & Development* **11**, 549-62.

Dahlberg, A.C. (2000b) Vegetation diversity and change in relation to land use, soil and rainfall - a case study from North-East District, Botswana. *Journal of Arid Environments* **44**, 19-40.

Daly, R.L. & Hodgkinson, K.C. (1996) Relationships between grass, shrub and tree cover on four landforms of semi-arid eastern Australia, and prospects for change by burning. *Rangeland Journal* **18**, 104-17.

Danin, A. (2008) Desert rocks – a habitat which supports many species that were new to science in the last 40 years. *Turkish Journal of Botany*, **32**, 459–464.

Daryanto, S. & Eldridge, D.J. (2012) Shrub hummocks as foci for small animal disturbances in an encroached shrubland. *Journal of Arid Environments* **80**, 35-9.

Davidson, W.H. (1920) Western experiences in 1885-1886. *Royal Geographical Society of Queensland* **5**, 43-59.

Davies, A.L. & Watson, F. (2007) Understanding the changing value of natural resources: an integrated palaeoecological-historical investigation into grazing woodland interactions by Loch Awe, Western Highlands of Scotland. *Journal of Biogeography* **34**, 1777 – 1791.

Davis, D.K. (2004) Desert ‘wastes’ of the Maghreb: desertification narratives in French colonial environmental history of North Africa. *Cultural Geographies* **11**, 359-87.

Davis, D.K. (2005) Indigenous knowledge and the desertification debate: problematising expert knowledge in North Africa. *Geoforum* **36**, 509–24.

Davis, R.C. (Ed.) 2002. *The Central Australian Expedition 1844-1846: The journals of Charles Sturt*. The Hakluyt Society, London.

Dawson, N.M. & Ahern, C.R. (1973) Soils and landscapes of mulga lands with special reference to south-west Queensland. *Tropical Grasslands* **7**, 23-34.

Dawson, N.M., Boyland, D.E., Ahern, C.R. (1975) Land management in south-west Queensland. *Proceedings of the Ecological Society of Australia* **9**, 124-141.

Dawson, T.J., Denny, M.J.S., Russell, E.M. & Ellis, B. (1975) Water usage and diet preferences of free ranging kangaroos, sheep and feral goats in the Australian arid zone during summer. *Journal of Zoology*, **177**, 1–23.

Dawson, T.J. & Ellis B.A. (1994) Diets of mammalian herbivores in Australian arid shrublands: seasonal effects on overlap between red kangaroos, sheep and rabbits and on dietary niche breadths and electivities. *Journal of Arid Environments* **26**, 257-71.

Dawson, T.J., McTavish, K.J, Munn, A.J., Holloway, J. (2006) Water use and the thermoregulatory behaviour of kangaroos in arid regions: insights into the colonisation of arid rangelands in Australia by the eastern grey kangaroo (*Macropus giganteus*). *Journal of Comparative Physiology B* **176**, 45-53.

Denham, A.J. & Auld, T.D. (2004) Survival and recruitment of seedlings and suckers of trees and shrubs of the Australian arid zone following habitat management and the outbreak of Rabbit Calicivirus Disease (RCD). *Austral Ecology* **29**, 585-99.

Denny, M.J.S. (1980) Red kangaroo arid zone studies. Australian National Parks and Wildlife Service, Canberra.

Denny, M.J.S. (1987) Historical and ecological study of the effects of European settlement on inland New South Wales. Nature Conservation Council of New South Wales, Sydney.

Denny, M.J.S. (1994) Investigating the past: an approach to determining the changes in the fauna of the Western Division of New South Wales since the first explorers. In Lunney, D., Hand, S., Reed, P., Butcher, D. (Eds.), *Future of the Fauna of Western New South Wales*. Royal Zooological Society of New South Wales, Mosman, pp. 53-63.

Department of Environment & Heritage Protection (2013) Guidelines for assessing and categorising species, populations and subpopulations. Available online at http://www.ehp.qld.gov.au/wildlife/threatened-species/guidelines.html [accessed 1 January 2014].

Department of Environment and Resource Management (2011) Quota Submission for Commercially Harvested Macropods in Queensland. Queensland Government, Brisbane. Available online at http://www.ehp.qld.gov.au/wildlife/permits-licences/pdf/2012-quota-submission.pdf [accessed 10 August 2012].

Díaz, S., Lavorel, S., McIntyre, S., Falczuk, V., Casanoves, F., Milchunas, D., Skarpe, C., Rusch, G., Sternberg, M., Noy-Meir, I., Landsberg, J., Zhang, W., Clark, H. & Campbell, B. (2007) Plant trait responses to grazing - a global synthesis. *Global Change Biology* **13**, 313-41.

Dickman, C.R., Pressey, R.L., Lim, L. & Parnaby, H.E. (1993) Mammals of particular conservation concern in the western division of New South Wales. *Biological Conservation* **65**, 219-48.

Division of Land Utilisation (1974) Western Arid Region Land Use Study Part I. Technical Bulletin 12. Division of Land Utilisation, Queensland Department of Primary Industries, Brisbane.

Division of Land Utilisation (1978) Western Arid Region Land Use Study Part IV. Technical Bulletin 23. Division of Land Utilisation, Queensland Department of Primary Industries, Brisbane.

Division of Land Utilisation (1979) Western Arid Region Land Use Study Part II. Technical Bulletin 22. Division of Land Utilisation, Queensland Department of Primary Industries, Brisbane.

Dixon, S. (1892) The effects of settlement and pastoral occupation in Australia upon the indigenous vegetation. *Transactions and Proceedings of the Royal Society of South Australia* **15**, 195-206.

Dodd, J.L. (1994) Desertification and degradation in sub-Saharan Africa: the role of livestock. *BioScience* **44**, 28-34.

D'Odorico, P., Okin, G. S. & Bestelmeyer, B. T. (2012) A synthetic review of feedbacks and drivers of shrub encroachment in arid grasslands. *Ecohydrology* **5**, 520-30.

Donaldson, T. (2002) What they call that in the whites?': Ngiyampaa and other place names in a New South Wales Ngurrampaa. In: *The Land is a Map: Place Names of Indigenous Origin in Australia* (Eds L. Hercus, F. Hodges & J. Simpson), pp. 207-38. Pandanus Books, Canberra.

Dowling, V.J. (1959-1863) Transcripts of V. J. Dowling's diaries for 1859, 1861 and 1863 June 14-Nov. 13. Manuscript reference no.: NLA MS 3032. Mitchell Library, Sydney.

Downing, B.H. (1986) Goat and sheep grazing in shrub-infested semi-arid woodlands of New South Wales. *Australian Rangeland Journal* **8**, 140-50.

Dregne, H. E. (1983) *Desertification of Arid Lands*. Harwood Academic Publishers, New York.

Dunk, P. (2010) *What More Could a Bloke Want?*. Unpublished memoirs of Peter Ernest Dunk, Warroo Station, Hungerford.

Durant, S.M., Pettorelli N., Bashir S., Woodroffe R., Wacher T., De Ornellas P., Ransom C., Abaigar T., Abdelgadir M., El Alqamy H., Beddiaf M., Belbachir F., Belbachir-Bazi A., Berbash A.A., Beudels-Jamar R., Boitani L., Breitenmoser C., Cano M., Chardonnet P., Collen B., Cornforth W.A., Cuzin F., Gerngross P., Haddane B., Hadjeloum M., Jacobson A., Jebali A., Lamarque F., Mallon D., Minkowski K., Monfort S., Ndoassal B., Newby J., Ngakoutou B.E., Niagate B., Purchase G., Samaila S., Samna A.K., Sillero-Zubiri C., Soultan A.E., Price M. R.S. & Baillie J.E.M. (2012) Forgotten biodiversity in desert ecosystems. *Science* **336**, 1379-80.

Duyker, E. (1983) Land use and ecological change in central New South Wales. *Journal of the Royal Australian Historical Society* **69**, 121-131.

Ealey, E.H.M. (1967) Ecology of the euro, *Macropus robustus* (Gould), in North Western Australia – II. Behaviour, movements, and drinking patterns. *Wildlife Research*, **12**, 27–51.

Edmonston, V. (2001) *Managing the Channel Country Sustainably: Producers' Experiences*. Queensland Department of Primary Industries, Brisbane.

Edwards, G.P., Dobbie, W. & Berman, D.M. (2002) Warren ripping: its impacts on European rabbits and other wildlife of central Australia amid the establishment of rabbit haemorrhagic disease. *Wildlife Research* **29**, 567–575.

Edwards, G.P., Pople, A.R., Saalfeld, K. & Caley, P. (2004) Introduced mammals in Australian rangelands: future threats and the role of monitoring programmes in management strategies. *Austral Ecology* **29**, 40-50.

Edwards, G.P., Zeng, B., Saalfeld, W.K. & Vaarzon-Morel, P. (2010) Evaluation of the impacts of feral camels. *Rangeland Journal* **32**, 43-54.

Ehrlén, J., Münzbergova, Z., Diekmann, M. & Eriksson, O. (2006) Long-term assessment of seed limitation in plants: results from an 11-year experiment. *Journal of Ecology* **94**, 1224–1232.

Eldridge, D.J. & James, A.I. (2009) Soil-disturbance by native animals plays a critical role in maintaining healthy Australian landscapes. *Ecological Management & Restoration* **10**, S27-S34.

Eldridge, D.J. & Lunt I. D. (2010) Resilience of soil seed banks to site degradation in intermittently flooded riverine woodlands. *Journal of Vegetation Science* **21**, 157-66.

Eldridge, D.J., Bowker, M.A., Maestre, F.T., Roger, E., Reynolds, J.F. & Whitford, W.G. (2011) Impacts of shrub encroachment on ecosystem structure and functioning: towards a global synthesis. *Ecology Letters* **14**, 709-22.

Eldridge, D.J., Val, J. & James, A.I. (2011) Abiotic effects predominate under prolonged livestock-induced disturbance. *Austral Ecology* **36**, 367-77.

Elhag, M.M. & Walker, S. (2010) Environmental degradation of natural resources in Butana area of Sudan. In: *Land Degradation and Desertification: Assessment, Mitigation and Remediation* (eds P. Zdruli, M. Pagliai, S. Kapur and A. Faz Cano). Springer, New York.

Ellis, C.J. (1981) *I Seek Adventure: an autobiographical account of pioneering experiences in outback Queensland from 1889 to 1904*. Alternative Publishing Cooperative Ltd, Sydney.

Ellis, J.E. & Swift, D.M. (1988) Stability of African pastoral ecosystems: alternate paradigms and implications for development. *Journal of Range Management* **41**, 450-9.

Environment Australia & Queensland Parks and Wildlife Service (1999) Rare and threatened species and plant communities of the Mulga Lands. Environmental Protection Agency, Brisbane.

Eriksson, O. & Jakobsson, A. (1998) Abundance, distribution and life histories of grassland plants: a comparative study of 81 species. *Journal of Ecology* **86,** 922–933.

Eriksson, O. (2013) Species pools in cultural landscapes – niche construction, ecological opportunity and niche shifts. *Ecography* **36**, 403–413.

Eshel, G. & Levy, G.J. (2007) Comments on ‘A fast method for determining soil particle size distribution using a laser instrumental by F. J. Arriaga, B. Lowery, and D. W. Mays. Soil Science 171 :663-674 (2006)’. *Soil Science* **172**, 413-5.

Fairfax, R.J. & Fensham, R.J. (2002) In the footsteps of J. Alfred Griffiths: a cataclysmic history of the Great Artesian Basin springs in Queensland. *Australian Geographical Studies* **40**, 210-230.

Fairfax, R.J., Fensham, R.J., Wager, R., Brook, S., Webb, A. & Unmack, P. (2007) Recovery of the red-finned blue-eye: an endangered fish from springs of the Great Artesian Basin. *Wildlife Research* **34**, 156-166.

Fairhead, J. & Leach, M. (1995) False forest history, complicit social analysis - rethinking some west-African environmental narratives. *World Development* **23**, 1023-35.

Fanning, P. (1999) Recent landscape history in arid western New South Wales, Australia: a model for regional change. *Geomorphology.* **29**, 191-209.

Farnsworth, E.J. & Ogurcak, D.E. (2006) Biogeography and decline of rare plants in New England: historical evidence and contemporary monitoring. *Ecological Applications* **16**, 1327-1337.

Fensham, R.J. (1997) Aboriginal fire regimes in Queensland, Australia: analysis of the explorers' record. *Journal of Biogeography* **24**, 11-22.

Fensham, R.J. (2008) Leichhardt’s maps: one hundred years of change in vegetation structure in inland Queensland. *Journal of Biogeography* **35**, 141-156.

Fensham, R.J., Donald, S. & Dwyer J.M. (2013) Propagule pressure, not fire or cattle grazing, promotes invasion of buffel grass Cenchrus ciliaris. *Journal of Applied Ecology* **50**, 138-46.

Fensham, R.J. & Fairfax, R.J. (2003) Spring wetlands of the Great Artesian Basin, Queensland, Australia. *Wetlands Ecology and Management* **11**, 343-362.

Fensham, R.J., Fairfax, R.J., Pocknee, D., Kelley, J. (2004a) Vegetation patterns in permanent spring wetlands of arid Australia. *Australian Journal of Botany* **52**, 719-728.

Fensham, R.J., Fairfax, R.J. & Sharpe, P.R. (2004b) Spring wetlands in seasonally arid Queensland: floristics, environmental relations, classification and conservation values. *Australian Journal of Botany* **52**, 583-595.

Fensham, R.J. & Fairfax, R.J. (2005) Preliminary assessment of gidgee (*Acacia cambagei*) woodland thickening in the Longreach district, Queensland. *Rangeland Journal* **27**, 159-168.

Fensham, R.J. & Fairfax, R.J. (2008) Water-remoteness for grazing relief in Australian arid-lands. *Biological Conservation* **141**, 1447-60.

Fensham, R. J., Fairfax, R. J. & Dwyer J. M. (2010a) Vegetation responses to the first 20 years of cattle grazing in an Australian desert. *Ecology* **91**, 681-92.

Fensham, R.J., Fairfax, R.J. & Dwyer, J.M. (2012) Potential aboveground biomass in drought-prone forest used for rangeland pastoralism. *Ecological Applications* **22**, 894-908.

Fensham, R.J. & Holman, J.E. (1999) Temporal and spatial patterns in drought-related tree dieback in Australian savanna. *Journal of Applied Ecology* **36**, 1035-1050.

Fensham, R.J., Holman, J.E. & Cox, M.J. (1999) Plant species responses along a grazing disturbance gradient in Australian grassland. *Journal of Vegetation Science* **10**, 77-86.

Fensham, R.J., Ponder, W.F. & Fairfax, R.J. (2010b) Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin. Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Department of Environment and Resource Management, Brisbane.

Fensham, R.J., Powell, O.C. & Horne, J. (2011a) Rail survey plans to remote sensing: vegetation change in the Mulga Lands of eastern Australia and its implications for land-use. *Rangeland Journal* **33**, 229-238.

Fensham, R.J. & Price, R.J. (2004) Ranking spring wetlands in the Great Artesian Basin of Australian using endemnicity and isolation of plant species. *Biological Conservation* **119**, 41-50.

Fensham, R.J., Silcock, J.L. & Dwyer, J.M. (2011b) Plant species richness responses to grazing protection and degradation history in a low productivity landscape. *Journal of Vegetation Science* **22**, 997-1008.

Fensham R. J., Silcock, J.L. & Firn, J. (2014) Managed livestock grazing is compatible with the maintenance of plant diversity in semidesert grasslands. *Ecological Applications* **24**, 503-17.

Fensham, R.J., Silcock, J.L., Kerezsy, A. & Ponder, W. (2011c) Four desert waters: setting arid zone wetland conservation priorities through understanding patterns of endemism. *Biological Conservation*, **144**, 2459–2467.

Fernandez-Gimenez, M.E. & Allen-Diaz, B. (1999) Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *Journal of Applied Ecology* **36**, 871-85.

Fiedler, P.L. & Ahouse, J.J. (1992) Hierarchies of cause: toward an understanding of rarity in vascular plants species. In *Conservation biology: the theory and practice of nature conservation management* (Eds P.L. Fiedler & S.K. Jain), pp. 23–48. Chapman and Hall, New York.

Field, J., Wroe, S., Trueman, C.N., Garvey, J. & Wyatt-Spratt, S. (2013) Looking for the archaeological signature in Australian Megafaunal extinctions. *Quaternary International* **285**, 76-88.

Finlayson, H.H. (1932) *Caloprymnus campestris*: its recurrence and characters. South Australian Museum, Adelaide.

Firn, J., Martin, T.G., Walters, B., Hayes, J., Nicol, S., Chades, I. & Carwardine, J. (2013) Priority Threat Management of Invasive Plants Species in the Lake Eyre Basin. CSIRO & Queensland University of Technology, Brisbane.

Fisher, A. (2001) Biogeography and conservation of Mitchell grasslands in northern Australia. PhD thesis, Charles Darwin University, Darwin.

Fjeldsa, J. & Lovett, J.C. (1997) Geographical patterns of old and young species in African forest biota: the significance of specific montane areas as evolutionary centres. *Biodiversity and Conservation* **6**, 325-346.

Flannery, T. (1994) *The Future Eaters*. Reed Books, Melbourne.

Flather, C.H. & Sieg, C.H. (2007) Species rarity: definition, causes and classification. In *Conservation of Rare or Little-Known Species: biological, social and economic considerations*. (Eds M.G. Raphael & R. Molina), pp. 40-66. Island Press, Washington.

Foran, B.D., Low, W.A. & Strong, B.W. (1985) The response of rabbit populations and vegetation to rabbit control on a calcareous shrubby grassland in central Australia. *Australian Wildlife Research* **12**, 237-47.

Forse, B. (1989) The myth of the marching desert. *New Scientist* **121**, 31-2.

Foster, D.R. (2000) From bobolinks to bears: interjecting geographical history into ecological studies, environmental interpretation, and conservation planning. *Journal of Biogeography* **27**, 27-30.

Forsyth, D.M., Parkes, J.P., Woolnough, A.P., Pickles, G., Collins, M. & Gordon, I. (2009) Environmental and economic factors determine the number of feral goats commercially harvested in Western Australia. *Journal of Applied Ecology* **46**, 101-9.

Franklin, D.C. (1999) Evidence of disarray amongst granivorous bird assemblages in savannas of northern Australia, a region of sparse human settlement. *Biological Conservation* **90**, 53-68.

Franks, A.J. (2002) The ecological consequences of buffel grass *Cenchrus ciliaris* establishment within remnant vegetation of Queensland. *Pacific Conservation Biology* **8**, 99-107.

Frie, E.S., Scheepens, J.F. & Stöcklin, J. (2012) Dispersal and microsite limitation of a rare alpine plant. *Plant Ecology*, **213**, 395–406.

Friedel, M.H. (1997) Discontinuous change in arid woodland and grassland vegetation along gradients of cattle grazing in central Australia. *Journal of Arid Environments* **37**, 145-64.

Friedel, M.H., Grice, A.C., Marshall, N.A. & van Klinken, R.D. (2011) Reducing contention amongst organisations dealing with commercially valuable but invasive plants: the case of buffel grass. *Environmental Science & Policy* **14**, 1205-18.

Friedel, M.H., Sparrow, A.D., Kinloch, J.E. & Tongway, D.J. (2003) Degradation and recovery processes in arid grazing lands of central Australia. Part 2: Vegetation. *Journal of Arid Environments* **55**, 327-48.

Fuhlendorf, S.D., Briske, D.D. & Smeins, F.E. (2001) Herbaceous vegetation change in variable rangeland environments: the relative contribution of grazing and climatic variability. *Applied Vegetation Science* **4**, 177–188.

Fukada, Y., McCallum, H.I., Grigg, G.C. & Pople, A.R. (2009) Fencing artificial waterpoints failed to influence density and distribution of red kangaroo (*Macropus rufus*). *Wildllife Research* **36**, 457-465.

Gale, S.J. & Haworth, R.J. (2005) Catchment wide soil loss from pre-agricultural time to the present: transport-and supply-limitation of erosion. *Geomorphology* **68**, 314-33.

Gammage, B. (2011) *The Biggest Estate on Earth: how Aborigines made Australia*. Allen & Unwin, Crows Nest, New South Wales.

Gammage, B. (1984) Tracing Sturt’s footsteps. *Journal of the Royal Australian Historical Society* **70**, 52-60.

Gammage, B. (2010) Galahs (the distribution of galahs in relation to Aboriginal and European settlement). *Australian Historical Studies* **40**, 275-293.

Gao, H., Bohn, T.J., Podest, E., McDonald, K.C. & Lettenmaier, D.P. (2011) On the causes of the shrinking of Lake Chad. *Environmental Research Letters* **6**, July-September: 034021.

Garnett, S.T., Szabo, J.K. & Dutson, G. (2011) *The Action Plan for Australian Birds 2010*. CSIRO Publishing, Collingwood.

Gasteen, W.J. (1982) Trends and condition of Queensland's arid and semi-arid lands. In: *What Future for Australia's Arid Lands?* (eds J. Messer and G. Mosley), pp. 152-5. Australian Conservation Foundation, Hawthorn, Victoria.

Gaston, K.J. (1994) *Rarity*. Chapman & Hall, London.

Gibson, N., Meissner, R., Markey, A.S. & Thompson, W.A. (2012) Patterns of plant diversity in ironstone ranges in arid south western Australia. *Journal of Arid Environments*, **77**, 25–31.

Gill, N. (2005) Life and death in Australian 'heartlands': pastoralism, ecology and rethinking the outback. *Journal of Rural Studies* **21**, 39-53.

Given, D.R. (1994) *Principles and Practice of Plant Conservation*. Timber Press, Portland.

Goforth, B.R. & Minnich, R.A. (2007) Evidence, exaggeration, and error in historical accounts of chaparral wildfires in California. *Ecological Applications* **1**, 779-790.

Golding, J.S. (2004) The use of specimen information influences the outcomes of Red List assessments: the case of southern African plant specimens. *Biodiversity and Conservation* **13**, 773–780.

Goldschmidt, W. (1981) The failure of pastoral development projects in Africa. In: *The Future of Nomadic Peoples* (eds J. Galaty, D. Aranson, P. Salzman & A. Chouinard). International Development Research Center, Ottowa.

Good, M.K., Price, J.N., Clarke, P.J. & Reid, N. (2012) Dense regeneration of floodplain *Eucalyptus coolabah*: invasive scrub or passive restoration of an endangered woodland community? *Rangeland Journal* **34**, 219-30.

Gordon, G., McGreevy, D.G., Lawrie, B.C. (1978) The yellow-footed rock wallaby, *Petrogale xanthopus* Gray (Macropodiae) in Queensland. *Australian Wildlife Research* **5**, 295-297.

Goriup, P.D. (1997) The world status of the Houbara bustard *Chlamydotis undulata*. *Bird Conservation International* **7**, 373-97.

Gott, B. (2005) Aboriginal fire management in south-eastern Australia: aims and frequency. *Journal of Biogeography* **32**, 1203-1208.

Gouldie, A.J. & Middleton, N.J. (2006) *Desert Dust in the Global System*. Springer, Heidelberg.

Graz, F.P. (2008) The woody weed encroachment puzzle: gathering pieces. *Ecohydrology* **1**, 340-8.

Greene, R.S.B. & Tongway, D.J. (1989) The significance of surface physical and chemical properties in determining soil surface condition of red earths in rangelands. *Australian Journal of Soil Research* **27**, 213-25.

Greene, R.S.B., Kinnell, P.I.A. & Wood, J.T. (1994) Role of plant cover and stock trampling on runoff and soil erosion from semi-arid wooded rangelands. *Australian Journal of Soil Research* **32**, 953-73.

Greenfell Thomas, R. (1919) Richard Greenfell Thomas's diaries of the first medical relief expedition amongst the Aborigines of southern Australia. Royal Geographic Society of Australasia, South Australian Branch, Adelaide.

Greenville, A.C., Dickman, C.R., Wardle, G.M., Letnic, M. (2009) The fire history of an arid grassland: the influence of antecedant rainfall and ENSO. *International Journal of Wildland Fire* **18**, 631-639.

Gregory, A.C. (1884) Expedition in Search of Dr Leichhardt - report of proceedings. In: Gregory, A.C. & Gregory, F.T. (Eds.), *Journals of Australian Explorations*, Government Printer, Sydney, pp.200-210.

Grice, A.C. & Barchia, I. (1992) Does grazing reduce survival of indigenous perennial grasses of the semiarid woodlands of western New South Wales. *Australian Journal of Ecology* **17**, 195-205.

Grice, A.C. (2004) Weeds and the monitoring of biodiversity in Australian rangelands. *Austral Ecology* **29**, 51-8.

Grice, A.C. (2006) The impacts of invasive plant species on the biodiversity of Australian rangelands. *Rangeland Journal* **28**, 27-35.

Griffin, G.F. & Friedel, M.H. (1985) Discontinuous change in central Australia: some implications of major ecological events for land management. *Journal of Arid Environments* **9**, 63-80.

Griffiths, M. & Barker, R. (1966) The plants eaten by sheep and kangaroos grazing together in a paddock in south-western Queensland. *Wildlife Research* **11**, 145-67.

Griffiths, T. (2001) One hundred years of environmental crisis. *The Rangeland Journal* **23**, 5-14.

Gross, J.E., Kneeland, M.C., Reed, D.F. & Reich, R.M. (2002) GIS-based habitat models for mountain goats. *Journal of Mammalogy*, **83**, 218–228.

Guthrie, W. (1940) Dust Bowl Ballads. Victor Records, New York City.

Hacker, R.B. & Alemseged, Y. (2014) Incorporating farmed goats into sustainable rangeland grazing systems in southern Australia: a review. *Rangeland Journal* **36**, 25-33.

Hacker, R.B., Hodgkinson, K.C., Melville, G.J., Bean, J. & Clipperton, S.P. (2006) Death Model for tussock perennial grasses: thresholds for grazing-induced mortality of mulga Mitchell grass (*Thyridolepis mitchelliana*). *The Rangeland Journal* **28**, 105-14.

Hall, A.V. (1987) Threatened plants in the Fynbos and Karoo Biomes, South Africa. *Biological Conservation* **40**, 29-52.

Hall, T.J. & Lee, G.R. (1980) Response of an Astrebla spp. grassland to heavy grazing by cattle and light grazing by sheep in north-west Queensland. *Australian Rangeland Journal* **2**, 83-93.

Hardy, B. (1969) *West of the Darling*. Jacaranda, Milton, Queensland.

Harper, J.L. (1981) The meanings of rarity. In *The Biological Aspects of Rare Plant Conservation* (Ed. H. Synge), pp. 189-203. John Wiley and Sons, Chichester.

Harrington, G.N. (1986) Herbivore diet in a semi-arid *Eucalyptus populnea* woodland. 2. Feral goats. *Australian Journal of Experimental Agriculture* **26**, 423-9.

Harris, W.G. & Loveday, R.J. (1862) Maps of John McKinlay’s route across the continent of Australia, From Stuckey’s Crossing to the Gulf of Carpentaria: compiled from Mr. McKinlay’s journal in the Office of the Surveyor General. Office of the Surveyor General, Adelaide.

Harrison, S. (1999) Local and regional diversity in a patchy landscape: native, alien, and endemic herbs on serpentine. *Ecology*, **80**, 70–80.

Harrison, S., Safford, H.D., Grace, J.B., Viers, J.H. & Davies, K.F. (2006) Regional and local species richness in an insular environment: serpentine plants in California. *Ecological Monographs*, **76**, 41–56.

Harshberger, J.W. (1903) The flora of the serpentine barrens of southeast Pennsylvania. *Science*, **18**, 339–343.

Hartley, W., Leigh, J. (1979) *Australian Plants At Risk*. Australian National Parks & Wildlife Service, Canberra.

Hassall, D.C. (1977) The genus *Euphorbia* in Australia. *Australian Journal of Botany*, **25**, 429–453.

Haynes, G.D., Gilligan, D.M., Grewe, P. & Nicholas, F.W. (2009) Population genetics and management units of invasive common carp *Cyprinus carpio* in the Murray-Darling Basin, Australia. *Journal of Fish Biology* **75**, 295-320.

Heathcote, R. L. (1983) *The Arid Lands : their use and abuse*. Longman, London.

Hellden, U. (1988) Desertification monitoring: is the desert encroaching? *Desertification Control Bulletin* **17**, 8-12.

Hercus, L. & Clarke, P. (1986) Nine Simpson Desert wells. *Archaeology in Oceania* **21**, 51-62.

Hernandez, H.M. & Barcena, R.T. (1996) Endangered cacti in the Chihuahuan Desert. II. Biogeography and conservation. *Conservation Biology* **10**, 1200-1209.

Herrmann, S.M. & Hutchinson, C.F. (2005) The changing contexts of the desertification debate. *Journal of Arid Environments* **63**, 538-55.

Herrmann, S. M., Anyamba, A. & Tucker, C.J. (2005) Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change-Human and Policy Dimensions* **15**, 394-404.

Hiernaux, P. (1998) Effects of grazing on plant species composition and spatial distribution in rangelands of the Sahel. *Plant Ecology* **138**, 191-202.

Hobbs, R.J., Cramer, V.J., Kristijanson, L.J. (2003) What happens if we cannot fix it? Triage, palliative care and setting priorities in salinising landscapes. *Australian Journal of Botany* **51**, 647-653.

Hodgkinson, K.C. & Harrington, G.N. (1985) The case for prescribed burning to control shrubs in eastern semi-arid woodlands. *Australian Rangeland Journal* **7**, 64-74.

Hodgkinson, K.C. (1998) Sprouting success of shrubs after fire: Height-dependent relationships for different strategies. *Oecologia* **115**, 64-72.

Hodgkinson, K.C. (2002) Fire regimes in Acacia wooded landscapes: effects on functional processes and biodiversity, In: Bradstock, R.A., Williams, J.E., Gill, M.A. (Eds.), *Flammable Australia: the fire regimes and biodiversity of a continent*. Cambridge University Press, Cambridge, pp. 259-277.

Hodgkinson, W.O. (1877) North-West Explorations, Parliamentary Papers (24 January), held by State Library of Queensland, Brisbane, pp. 203-226.

Holdaway, S.J., Fanning, P.C. & Witter, D.C. (2000) Prehistoric aboriginal occupation of the rangelands: interpreting the surface archaeological record of far western New South Wales. *Rangeland Journal* **22**, 44-57.

Holgrem, M., Stapp, P., Dickman, C.R., Gracia, C., Graham, S., Gutierrez, J.R., Hice, C., Jaksic, F., Kelt DA, Letnic M, Lima M, Lopez BC, Meserve PL, Milstead WB, Polis GA, Previtali MA, Richter M, Sabate, S., Squeo, F.A. (2006) Extreme climatic events shape arid and semiarid ecosystems. *Frontiers in Ecology and Environment* **4**, 87-95.

Hone, J. (1995) Spatial and temporal aspects of vertebrate pest damage with emphasis on feral pigs. *Journal of Applied Ecology* **32**, 311-9.

Hopper, S.D. & Gioia, P. (2004) The Southwest Australian Floristic Region: evolution and conservation of a global hot spot of biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, **35**, 623–650.

Howard, K.S.C., Eldridge, D.J. & Soliveres, S. (2012) Positive effects of shrubs on plant species diversity do not change along a gradient in grazing pressure in an arid shrubland. *Basic and Applied Ecology* **13**, 159-68.

Hunt, L.P. (2001) Heterogeneous grazing causes local extinction of edible perennial shrubs: a matrix analysis. *Journal of Applied Ecology* **38**, 238-52.

Hunt, L.P. (2010) Spatial variation in the demography and population dynamics of a perennial shrub (*Atriplex vesicaria*) under sheep grazing in semi-arid Australian rangelands. *Austral Ecology* **35**, 794-805.

Idris, H. (1996) Springs in Egypt. *Environmental Geology* **27**, 99-104.

Illius, A.W. & O'Connor, T.G. (1999) On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. *Ecological Applications* **9**, 798-813.

Imeson, A.C. (2012) *Desertification, Land Degradation and Sustainability*, Blackwell-Wiley, New Jersey.

IUCN (2001). International Union for the Conservation of Nature Red List Categories. Version 3.1. Prepared by the IUCN Species Survival Commission. World Conservation Union, Gland, Switzerland and Cambridge, United Kingdom

Jackson, J. (2005) Is there a relationship between herbaceous species richness and buffel grass (*Cenchrus ciliaris*)? *Austral Ecology* **30**, 505-17.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R. (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629-638.

Jackson, R.D. & Bartoleme, J.W. (2002) A state-transition approach to understanding nonequilibrium plant community dynamics in Californian grasslands. *Plant Ecology* **162**, 49-65.

Jacobsen T. & Adams R. M. (1958) Salt and silt in ancient Mesopotamian agriculture. *Science* **128**, 1251-8.

James, C.D., Landsberg, J. & Morton, S.R. (1999) Provision of watering points in the Australian arid zone: a review of effects on biota. *Journal of Arid Environments* **41**, 87-121.

Jessup, J. (Ed.) (1981) *Flora of Central Australia*. Australian Systematic Botany Society, Reed Books Pty Ltd, Sydney.

Jiao, J.J. (2010) Crescent Moon Spring: a disappearing natural wonder in the Gobi Desert, China. *Groundwater* **48**, 159-63.

Jobson, R. (2013) Five new species of *Utricularia* (Lentibulariaceae) from Australia. *Telopea* **15**, 127-142.

Johnson, B.J., Miller, G.H., Magee, J.W., Gagan, M.K., Fogel, M.L. & Quay, P.D. (2005) Carbon isotope evidence for an abrupt reduction in grasses coincident with European settlement of Lake Eyre, South Australia. *The Holocene* **15**, 888-96.

Johnson, C.N. (2006) *Australia's Mammal Extinctions: a 50,000 year history*. Cambridge University Press, Port Melbourne.

Johnson, C.N. & Isaacs, J.L. (2009) Body mass and extinction risk in Australian marsupials: the 'critical weight range' revisited. *Austral Ecology* **34**, 35-40.

Johnson, C.N., Isaacs, J.L. & Fisher, D.O. (2007) Rarity of a top predator triggers continent-wide collapse of mammal prey: dingoes and marsupials in Australia. *Proceedings of the Royal Society B* **274**, 341-6.

Jones, P. & Burrows, W.H. (1994) State and transition models for rangelands. 13. a state and transition model for the mulga zone of south-west Queensland. *Tropical Grasslands* **28**, 279-83.

Joseph, L.N., Maloney, R.F. & Possingham, H.P. (2007) Optimal allocation of resources among threatened species: a project prioritization protocol. *Conservation Biology*, **23**, 328-338.

Jurado, E. & Westoby, M. (1992) Germination biology of selected central Australian plants. *Australian Journal of Ecology* **17**, 341-348.

Kadmon, R., Farber, O., Danin, A. (2004) Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. *Ecological Applications* **14**, 401-413.

Karst, J., Gilbert, B. & Lechowicz, M.J. (2005) Fern community assembly: the roles of chance and the environment at local and intermediate scales. *Ecology*, **86**, 2473-2486.

Keighery, G.J., Gibson, N., Van Leeuwen, S., Lyons, M.N. & Patrick, S. (2007) Biological survey and setting priorities for flora conservation in Western Australia. *Australian Journal of Botany* **55**, 308-315.

Keith, D.A. (1998) An evaluation and modification of World Conservation Union Red List Criteria for classification of extinction risk in vascular plants. *Conservation Biology* **12**, 1076-1090.

Keith, D.A. (2000) Sampling designs, field techniques and analytical methods for systematic plant population surveys. *Ecological Management and Restoration* **1**, 125-139.

Kennedy, M.., Phillips, B.L., Legge, S., Murphy, S.A. & Faulkner, R.A. (2012) Do dingoes suppress the activity of feral cats in northern Australia? *Austral Ecology* **37**, 134-9.

Kerezsy, A. & Fensham, R.J. (2013) Conservation of the endangered red-finned blue-eye, *Scaturiginichthys vermeilipinnis*, and control of alien eastern gambusia, *Gambusia holbrooki*, in a spring wetland complex. *Marine and Freshwater Research* **64**, 851-63.

Kerezsy, A. (2010) The distribution, recruitment and movement of fish in far western Queensland. PhD thesis, Griffith University, Brisbane.

Kerle, J.A., Foulkes, J.N., Kimber, R.G. & Papenfus, D. (1992) The decline of the brushtail possum, *Trichosurus vulpecular* (Kerr 1798) in arid Australia. *Rangeland Journal* **14**, 107-127.

Khairo, S.A., Hacker, R.B., Atkinson, T.L. & Turnbull, G.L. (2013) Alternative strategies for management of feral goats: implications for natural resource management policies in New South Wales rangelands. *Rangeland Journal* **35**, 201-10.

Khalaf, F.I. & Alajmi, D. (1993) Aeolian processes and sand encroachment problems in Kuwait. *Geomorphology* **6**, 111-34.

Khan, T.I., Dular, A.K. & Solomon, D.M. (2003) Biodiversity conservation in the Thar Desert, with emphasis on endemic and medicinal plants. *The Environmentalist* **23**, 137-144.

Kimber, R.G. (1983) Black lightning: Aborigines and fire in Central Australia and the Western Desert. *Archaeology in Oceania* **18**, 38-45.

Kirkpatrick, J.B. (2007) Collateral benefit: unconscious conservation of threatened plant species. *Australian Journal of Botany* **55**, 221-224.

Knighton, A.D. & Nanson, G.C. (1994) Waterholes and their significance in the anastomosing channel system of Cooper Creek, Australia. *Geomorphology* **9**, 311-324.

Kotlyakov, V.M. (1991) The Aral Sea basin: a critical environmental zone. *Environment* **33**, 36-8.

Kowald, M. & Johnson, W.R. (1992) *You Can't Make It Rain: the story of the North Australian Pastoral Company, 1887-1991*. Boolarong Publications, Brisbane.

Kruckenberg, R. & Rabinowitz, D. (1985) Biological aspects of endemism in higher plants. *Annual Review of Ecology and Systematics*, **16**, 447–479.

Kumar, S. & Mathur, M. (2014) Impact of invasion by *Prosopis juliflora* on plant communities in arid grazing lands. *Tropical Ecology* **55**, 33-46.

Kunin, W.E. & Gaston, K.J. (1993) The biology of rarity: patterns, causes and consequences. *Trends in Ecology and Evolution* **8**, 298-301.

Lahav-Ginott, S., Kadmon, R. & Gersani, M. (2001) Evaluating the viability of Acacia populations in the Negev Desert: a remote sensing approach. *Biological Conservation* **98**, 127-37.

Laliberte, A.S. & Ripple, W.J. (2004) Range contractions of North American carnivores and ungulates. *BioScience* **54**, 123-38.

Lamprey, H. (1988) Report on the desert encroachment reconnaissance in northern Sudan: 21 October to 10 November 1975. *Desertification Control Bulletin* **17**, 1-7.

Landsberg, J. & Clarkson, J. (2004) Threatened plants of Cape York Peninsula. Report to Australian Government Department of Environment and Heritage. Queensland Parks and Wildlife Service, Cairns.

Landsberg, J., James, C.D., Maconochie, J., Nicholls, A.O., Stol, J. & Tynan, R. (2002) Scale-related effects of grazing on native plant communities in an arid rangeland region of South Australia. *Journal of Applied Ecology* **39**, 427-44.

Landsberg, J., James, C.D., Morton, S.R., Hobbs, T.J., Stol, J., Drew, A. & Tongway, H. (1997) The Effects of Artificial Sources of Water on Rangeland Biodiversity. Final report to the Biodiversity Conservation and Strategy Section of the Biodiversity Group. Environment Australia, Canberra.

Landsberg, J., James, C.D., Morton, S.R. & Muller, W.J. (2003) Abundance and composition of plant species along grazing gradients in Australian rangelands. *Journal of Applied Ecology* **40**, 1008-24.

Landsberg, J. & Stol, J. (1996) Spatial distribution of sheep, feral goats and kangaroos in woody rangeland paddocks. *The Rangeland Journal* **18**, 270-91.

Landsborough, W. (1862) *Journal of Landsborough's expedition from Carpentaria in search of Burke and Wills with a map showing his route*. F.F. Bailliere, Melbourne.

Lange, R.T. & Graham, C.R. (1983) Rabbits and the failure of regeneration in Australian arid zone Acacia. *Australian Journal of Ecology* **8**, 377–81.

Lange, R.L. & Willcocks, M.C. (1980) Experiments on the capacity of present sheep flocks to extinguish some tree populations of the South Australian arid zone. *Journal of Arid Environments* **3**, 223-9.

Latz, P. (2007) *The Flaming Desert*. Peter Latz, Alice Springs.

Lavergne, S., Thuiller, W., Molina, J. & Debussche, M. (2005) Environmental and human factors influencing rare plant local occurrence, extinction and persistence: a 115-year study in the Mediterranean region. *Journal of Biogeography*, **32**, 799–811.

Leigh, J.H., Briggs, J., Hartley, W. (1981) Rare or Threatened Australian Plants. Australian National Parks and Wildlife Service, Canberra.

Leigh, J.H., Wood, D.H., Holgate, M.D., Slee, A. & Stanger, M.G. (1989) Effects of rabbit and kangaroo grazing on two semi-arid grassland communities in central western New South Wales. *Australian Journal of Botany* **37**, 375-96.

Letnic, M. (2000) Dispossession, degradation and extinction: environmental history in arid Australia. *Biodiversity and Conservation* **9**, 295-308.

Lewis, J.H. (1876) Journal of Mr Lewis's Lake Eyre Expedition, Parliamentary Papers of South Australian Parliament, Adelaide.

Li, C.L., Jiang, Z.G., Fang, H.X. & Li, C.W. (2013) A spatially explicit model of functional connectivity for the endangered Przewalski's gazelle (*Procapra przewalskii*) in a patchy landscape. *Plos One* **8**, issue 11.

Lim, T.L. & Giles, J.R. (1987) Studies on yellow-footed rock wallaby, *Petrogale xanthopus* Gray (Marsupialia: Macropodiae) III. Distribution and management in western New South Wales. *Australian Wildlife Research* **14**, 147-161.

Lister, A.M. & Climate Change Research Group (2011) Natural history collections as sources of long-term datasets. *Trends in Ecology and Evolution* **26**, 153-154.

Loew, F., Navratil, P., Kotte, K., Scholer, H.F. & Bubenzer, O. (2013) Remote-sensing-based analysis of landscape change in the desiccated seabed of the Aral Sea: a potential tool for assessing the hazard degree of dust and salt storms. *Environmental Monitoring and Assessment* **185**, 8303-19.

Loranzo, F.D., Saiz, J.C.M & Ollero, H.S. (2003) Rarity and threat relations in the conservation planning of Iberian flora. *Biodiversity and Conservation* **12**, 1861-1882.

Lorentz, P. (1936) *The Plow That Broke the Plain (Film)*. United States Resettlement Administration.

Luiz, O.J., Edwards, A.J. (2011) Extinction of a shark population in the Archipelago of Saint Paul's Rocks (equatorial Atlantic) inferred from the historical record. *Biological Conservation* **144**, 2873-2881.

Lundie-Jenkins, G. & Payne, A. (2000) Recovery Plan for the Julia Creek dunnart (*Sminthopsis douglasi*) 2000-2004. Queensland National Parks & Wildlife Service, Brisbane.

Lunney, D. (2001) Causes of the extinction of native mammals of the Western Division of New South Wales: an ecological interpretation of the nineteenth century historical record. *The Rangeland Journal* **23**, 44-70.

Lunt, I. (1998) Two hundred years of land use and vegetation change in remnant coastal woodland in southern Australia. *Australian Journal of Botany* **46**, 629-647.

Mabbutt, J.A. (1984) A new global assessment of the status and trends of desertification. *Environmental Conservation* **11**, 103-13.

Mabbutt, J.A. (1986) Desertification indicators. *Climatic Change* **9**, 113-22.

Mabit, L., Benmansour, M. & Walling, D.E. (2008) Comparative advantages and limitations of the fallout radionuclides Cs-137, Pb-210(ex) and Be-7 for assessing soil erosion and sedimentation. *Journal of Environmental Radioactivity* **99**, 1799-807.

MacDougall, A.S. (2008) Herbivory, hunting, and long-term vegetation change in degraded savanna. *Biological Conservation* **141**, 2174-2183.

MacDougall, A.S., Loo, J.A., Clayden, S.R., Goltz, J.G. & Hinds, H.R. (1998) Defining conservation priorities for plant taxa in southeastern New Brunswick, Canada using herbarium records. *Biological Conservation* **86**, 325-338.

Mace, G.M., Collar, N.J., Gaston, K.J., Hilton-Taylor, C., Akcakaya, H.R., Leader-Williams, N., Milner-Gulland, E.J. & Stuart, S.N. (2008) Quantification of extinction risk: IUCN's system for classifying threatened species. *Conservation Biology* **22**, 1424-1442.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. & Bazzaz F.A. (2000) Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* **10**, 689-710.

Maconochie, J.R. (1982) Regeneration of arid zone plants: a floristic survey. In *Evolution of the Flora and Fauna of Arid Australia* (Eds W.R. Barker & P.J.M. Greenslade), pp. 141-144. Peacock Publications, Adelaide.

Magee, J.W., Miller, G.H., Spooner, A.N. & Questiaux, D. (2009) Continuous 150 k.y. monsoon record from Lake Eyre, Australia: insolation-forcing implications and unexpected Holocene failure. *Geology* **32**, 885-888.

Marcot, B.G. & Molina, R. (2007) Special considerations for the science, conservation and management of rare or little-known species, In *Conservation of Rare or Little-Known Species: biological, social and economic considerations*. (Eds M.G. Raphael & R. Molina), pp. 93-124. Island Press, Washington.

Marsh, G.P. (1965) *Man and Nature (published 1864)*. Belknap Press of Harvard University Press, Cambridge.

Marshall, A.J. (1966) *The Great Extermination: a guide to Anglo-Australian cupidity wickedness and waste*. William Heinemann Ltd, Melbourne.

Martorell, C. & Peters, E.M. (2005) The measurement of chronic disturbance and its effects on the threatened cactus *Mammillaria pectinifera*. *Biological Conservation*, **124**, 199–207.

Maslin, B.R. (2001) WATTLE: Acacias of Australia (electronic resource). Australian Biological Resources Study, Canberra.

Matthes, U. & Larson, D.W. (2006) Microsite and climatic controls of tree population dynamics: an 18-year study on cliffs. *Journal of Ecology*, **94**, 402–414.

McDonald, L.L. (2004) Sampling rare populations, In *Sampling Rare or Elusive Species: concepts, designs, and techniques for estimating population parameters*. (ed. W.L. Thompson), pp. 11-42. Island Press, Washington.

McIntyre, S. (1992) Risks associated with the setting of conservation priorities from rare plant species lists. *Biological Conservation* **60**, 31-37.

McKenzie, N.L., Burbidge, A.A., Baynes, A., Brereton, R.N., Dickman, C.R., Gordon, G., Gibson, L.A., Menkhorst, P.W., Robinson, A.C., Williams, M.R. & Woinarski, J.C.Z. (2007) Analysis of factors implicated in the recent decline of Australia's mammal fauna. *Journal of Biogeography* **34**, 597-611.

McKeon G., Hall W., Henry B., Stone G. & Watson I. (2004) *Pasture Degradation and Recovery in Australia's Rangelands: learning from history*. Queensland Department of Natural Resources, Mines and Energy, Brisbane.

McKinlay, J.M. (1863) Explorations in the interior of Australia by the Burke relief expedition. *Proceedings of the Royal Geographic Society of London* **7**, 84-90.

McMahon, T.A., Murphy, R.E., Peel, M.C., Costelloe, J.F. & Chiew, F.H.S. (2008) Understanding the surface hydrology of the Lake Eyre Basin: Part 2 – streamflow. *Journal of Arid Environments* **72**, 1869-1886.

McManus, M. (1916) *Reminiscences of the early settlement of the Maranoa District in the late fifties and early sixties*. E.A. Howard, Brisbane.

McNeely, J. A. (2003) Biodiversity in arid regions: values and perceptions. *Journal of Arid Environments* **54**, 61-70.

McRae, P. D. (2004) Aspects of the Ecology of the Grea ter Bilby, *Macrotis lagotis*, in Queensland. Masters Thesis, University of Sydney, Sydney.

McTainsh, G.H., Chan, Y.-C., McGowan, H., Leys, J. & Tews, K. (2005) The 23rd October 2002 dust storm in eastern Australia: characteristics and meteorological conditions. *Atmospheric Environment* **39**, 1227-36.

Médail, F. & Diadema, K. (2009) Glacial refugia influence plant diversity patterns in the Mediterranean Basin. *Journal of Biogeography*, **36**, 1333–1345.

Meyer, S.E. (1986) The ecology of gypsophile endemism in the eastern Mojave Desert. *Ecology* **67**, 1303-1313.

Migliore, J., Baumel, A., Juin, M., Fady, B., Roig, A., Duong, N. & Médail, F. (2013) Surviving in mountain climate refugia: new insights from the genetic diversity and structure of the relict shrub *Myrtus nivellei* (Myrtaceae) in the Sahara Desert. *PLoS ONE*, **8**, e73795.

Milchunas, D.G. & Lauenroth, W.K. (1993) Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* **63**, 327-66.

Milchunas, D.G. & Noy-Meir, I. (2002) Grazing refuges, external avoidance of herbivory and plant diversity. *Oikos*, **99**, 113–130.

Milchunas, D.G., Sala, O.E. & Lauenroth, W.K. (1988) A generalised model of the effects of grazing by large herbivores on grassland community structure. *American Naturalist* **132**, 87-106.

Miles, R.L. (1993) Soil Degradation Processes in a Semi-Arid Woodland. PhD thesis, School of Australian Environmental Studies, Griffith University, Brisbane.

Miller, G.H., Fogel, M.L., Magee, J.W., Gagan, M.K., Clarke, S.J. & Johnson B.J. (2005) Ecosystem collapse in Pleistocene Australia and a human role in megafaunal extinction. *Science* **309**, 287-90.

Miller, G., Friedel, M., Adam, P. & Chewings V. (2010) Ecological impacts of buffel grass (Cenchrus ciliaris L.) invasion in central Australia - does field evidence support a fire-invasion feedback? *Rangeland Journal* **32**, 353-65.

Mills, J.R. (1986) Degradation and rehabilitation of the mulga ecosystem, In: Sattler, P.S. (Ed.) *The Mulga Lands*. Royal Society of Queensland, Brisbane, pp. 79-83.

Mills, J.R., Turner, E.J. & Caltobiano, T. (1989) Land degradation in South-Western Queensland. Queensland Department of Primary Industries, Brisbane.

Mills, J.R., Ahern, C.R., Purdie, R.W. & McDonald, W.J.F. (1990) Western Arid Region Land Use Study Part III. Technical Bulletin 29. Division of Land Utilisation, Queensland Department of Primary Industries, Brisbane.

Milson, J. (2000a) *Pasture Plants of North-West Queensland*. Queensland Department of Primary Industries, Brisbane.

Milson, J (2000b) *Trees and Shrubs of North-West Queensland*. Queensland Department of Primary Industries, Brisbane.

Milton, S.J. & Dean, W.R.J. (1995) South Africa's arid and semiarid rangelands: why are they changing and can they be restored? *Environmental Monitoring and Assessment* **37**, 245-64.

Milton, S.J., Dean, W.R.J., du Plessis, M.A. & Siegfried, W.R. (1994) A conceptual model of arid rangeland degradation. *BioScience* **44**, 70-6.

Minchin, P.R. (1991) DECODA user's manual. Research School of Pacific Studies, Australian National University, Canberra.

Minnis, P.E. (2000) Prehistoric agriculture and anthropogenic ecology of the North American Southwest. In: *The Archaeology of Drylands: Living at the Margin* (eds G. Barker & D. Gilbertson), pp. 271–87. Routledge, London.

Mitchell, P.B. (1991) Historical perspectives on some vegetation and soil changes in semi-arid New South Wales. *Vegetatio* **91**, 169-82.

Mitchell, T.L. (1847) *Journal of an Expedition into Tropical Australia in Search of a Route from Sydney to the Gulf of Carpentaria*. University of Adelaide Library Electronic Texts Collection, http://ebooks.adelaide.edu.au/m/mitchell/thomas [accessed 1 September 2007].

Mokany, K. & Adam, P. (2000) The biogeographical attributes of the threatened flora of New South Wales. *Cunninghamia* **6**, 873-892.

Montague-Drake, R. & Croft, D.B. (2004) Do kangaroos exhibit water-focussed grazing patterns in arid New South Wales? *Australian Mammalogy*, **26**, 87–100.

Moore, R.M. & Walker, J. (1972) *Eucalyptus populnea* shrub woodlands: control of regenerating trees and shrubs. *Australian Journal of Experimental Agriculture and Animal Husbandry* **12**, 437-40.

Moore, J.L., Howden, S.M., McKeon, G.M., Carter, J.O. & Scanlan, J.C., 2001. The dynamics of grazed woodlands in southwest Queensland, Australia and their effect on greenhouse gas emissions. *Environment International* **27**, 147-153.

Moore, K.A. & Elmendorf, S.C. (2006) Propagule vs. niche limitation: untangling the mechanisms behind plant species' distributions. *Ecology Letters*, **9**, 797–804.

Morrison, D.A., Le Broque, A.F. & Clarke, P.J. (1995) An assessment of some improved techniques for estimating the abundance (frequency) of sedentary organisms. *Vegetatio* **120**, 131-45.

Morse, L.E. (1996) Plant rarity and endangerment in North America. In *Restoring Diversity: reintroduction of endangered plants*. (Eds DA Falk, CI Millar, M Olwell), pp. 7-22. Island Press, Washington DC.

Morton, S.R. (1990) The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. *Proceedings of the Ecological Society of Australia* **16**, 201-13.

Morton, S.R., Stafford Smith, D. M., Dickman, C.R., Dunkerley, D.L., Friedel, M.H., McAllister, R.R.J., Reid, J.R.W., Roshier, D.A., Smith, M.A., Walsh, F.J., Wardle, G.M., Watson, I.W. & Westoby, M. (2011) A fresh framework for the ecology of arid Australia. *Journal of Arid Environments* **75**, 313-29.

Moseby, K.E. & Kemper, C. (2008) *Pseudomys australis*. The IUCN Red List of Threatened Species. Version 2014.2. Online at www.iucnredlist.org [accessed 20 July 2014].

Moustafa, A.E.A. & Zaghloul, M.S. (1996) Environment and vegetation in the montane Saint Catherine area, south Sinai, Egypt. *Journal of Arid Environments*, **34**, 331–349.

Murray, B.R., Rice, B., Keith, D.A., Myerscough, P.J., Floyd, A.G., Mills, K. & Westoby, M. (1999) Species in the tail of rank-abundance curves. *Ecology* **80**, 1806-1816.

Muturi, G.M., Poorter, L., Mohren, G.M.J. & Kigomo, B.N. (2013) Ecological impact of *Prosopis* species invasion in Turkwel riverine forest, Kenya. *Journal of Arid Environments* **92**, 89-97.

Nanson, G.C., Price, D.M., Jones, B.G., Maroulis, J.C., Coleman, M., Bowman, H., Cohen, T.J., Pietsch, T.J., Larsen, J.R. (2008) Alluvial evidence for major climate and flow regime changes during the middle and late Quaternary in eastern Australia. *Geomorphology* **101**, 109-129.

Nash, M.S., Whitford, W., de Soyza, A.G., Van Zee, J.W. & Havstad, K.M. (1999) Livestock activity and Chihuahuan Desert annual-plant communities: boundary analysis of disturbance gradients. *Ecological Applications* **9**, 814-23.

Nater, T., Duchrow, A. & Sörensen, L. (2008) Desertification: coping with today's global challenges in the context of the strategy of the United Nations Convention to Combat Desertification. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), High-Level Policy Dialogue, Bonn, May 27, 2008.

New South Wales National Parks and Wildlife Service (2000) Flame spider flower (*Grevillea kennedyana*) recovery plan. NSW National Parks and Wildlife Service: Hurtsville.

Newsome, A.E. (1965) The distribution of red kangaroos, *Megalia rufa* (Desmarest), about sources of persistent food and water in central Australia. *Australian Journal of Zoology*, **13**, 289–299.

Newsome, A.E. (1975) An ecological comparison of the two arid-zone kangaroos of Australia, and their anomalous prosperity since the introduction of ruminant stock to their environment. *Quarterly Review of Biology* **50**, 389-424.

Noble, J.C. (1997) *The Delicate and Noxious Scrub: CSIRO studies on native tree and shrub proliferation in the semi-arid woodlands of eastern Australia*. CSIRO, Canberra.

Noble, J.C., Muller, W.J., Detling, J.K. & Pfitzner, G.H. (2007) Landscape ecology of the burrowing bettong: warren distribution and patch dynamics in semiarid eastern Australia. *Austral Ecology* **32**, 326-37.

Nolan, C. (2003) *Sandhills and Channel Country*. Diamantina Shire Council, Bedourie.

Norman, P., Denham, R. & Calvert, M. J. (2014) Life histories of two arid-zone shrubs change with differences in habitat, grazing and climate. *Rangeland Journal* **36**, 249-57.

Noumi, Z., Touzard, B., Michalet, R. & Chaieb, M. (2010) The effects of browsing on the structure of *Acacia tortilis* (Forssk.) Hayne ssp *raddiana* (Savi) Brenan along a gradient of water availability in arid zones of Tunisia. *Journal of Arid Environments* **74**, 625-31.

Noy-Meir, I. (1973) Desert ecosystems: environment and producers. *Annual Review of Ecology and Systematics* **4**, 25-51.

Oba, G., Stenseth, N.C. & Lusigi, W.J. (2000) New perspectives on sustainable grazing management in arid zones of sub-saharan Africa. *Bioscience* **50**, 35-50.

O'Connor, T.G. & Roux, P.W. (1995) Vegetation changes (1949-71) in a semi-arid, grassy dwarf shrubland in the Karoo, South Africa: Influence of rainfall variability and grazing by sheep. *Journal of Applied Ecology* **32**, 612-26.

Ogle, K. & Reynolds, J.F. (2004) Plant responses to precipitation in desert ecosytems: integrating functional types, pulses, thresholds, and delays. *Oecologia* **141**, 282-294.

Okin, G.S., Murray, B. & Schlesinger, W.H. (2001) Degradation of sandy arid shrubland environments: observations, process modelling, and management implications. *Journal of Arid Environments* **47**, 123-44.

Orr, D.M. (1981) Changes in the quantitative floristics in some Astrebla spp. (Mitchell Grass) communities in south-western Queensland in relation to trends in seasonal rainfall. *Australian Journal of Botany* **29**, 533-45.

Orr, D.M. (1991). Trends in the recruitment of *Astrebla* spp. in relation to seasonal rainfall. *Rangeland Journal* **13**, 107-117.

Orr, D.M. (1992) *Astrebla* grasslands - a resilient ecosystem. Conference Proceedings, 7th Biennial Conference, The Australian Rangeland Society.

Orr, D.M., Evenson, C.J., Lehane, J.K., Bowly, P.S. & Cowan, D.C. (1993) Dynamics of perennial grasses with sheep grazing in *Acacia aneura* woodlands in south-west Queensland. *Tropical Grasslands* **27**, 87-93.

Orr, D.M. & Phelps, D.G. (2013) Impacts of level of utilisation by grazing on an *Astrebla* (Mitchell grass) grassland in north-western Queensland between 1984 and 2010. 2. Plant species richness and abundance. *Rangeland Journal* **35**, 17-28.

Osmond, R. (2003) Control and management options for mesquite (*Prosopis* spp.) in Australia. Department of Natural Resources and Mines, Brisbane.

Oxley, R.E. (1987a) Analysis of historical records of a grazing property in south-western Qld. 1. Aspects of the patterns of development and productivity. *Australian Rangeland Journal* **9**, 21-9.

Oxley, R.E. (1987b) Analysis of historical records of a grazing property in South-Western Queensland 2. Vegetation changes. *Australian Rangeland Journal* **9**, 30-8.

Parkes, J., Henzell, R. & Pickles G. (1996) Managing vertebrate pests: Feral goats. Bureau of Resource Sciences/CSIRO Division of Wildlife and Ecology, Canberra.

Parmentier, I., Stévart, T. & Hardy, O.J. (2005) The inselberg flora of Atlantic Central Africa. I. Determinants of species assemblages. *Journal of Biogeography*, **32**, 685–696.

Parsons, R.F. (2000) Enrichment-planting of the woody climbers *Marsdenia australis* and *Rhyncharrhena linearis* in north-western Victoria. *Proceedings of the Royal Society of Victoria* **128**, 61-66.

Parsons, R.F. & Browne, J.H. (1982) Causes of plant species rarity in semi-arid southern Australia. *Biological Conservation* **24**, 183-192.

Parsons, W.T. & Cuthbertson, E.G. (2001) *Noxious Weeds of Australia (2nd edn).* CSIRO Publishing, Collingwood.

Partel, M., Kalamees, R., Reier, U., Tuvi, E.L., Roosaluste, E., Vellak, A., Zobel, M., (2005) Grouping and prioritization of vascular plant species for conservation: combining natural rarity and management need. *Biological Conservation* **123**, 271-278.

Patten, D.T., Rouse, L. & Stromberg, J.C. (2008) Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: Potential response of vegetation to groundwater withdrawal. *Environmental Management* **41**, 398-413.

Pearce, T. & Bytebier, B. (2002) The role of an herbarium and its database in supporting plant conservation. In *Plant Conservation in the Tropics: perspectives and practice* (Eds M. Maunder, C. Clubbe, C. Hankamer, M. Groves), pp.49-67. Royal Botanic Gardens, Kew.

Perevolotsky, A. & Seligman, N. (1998) Role of grazing in Mediterranean rangeland ecosystems. *BioScience* **48**, 1007-17.

Perkins, J.S. & Thomas, D.S.G. (1993) Environmental responses and sensitivity to permanent cattle ranching, semi-arid western central Botswana. In: *Landscape Sensitivity* (eds D. S. G. Thomas and R. J. Allison), pp. 273-86. John Wiley and Sons, Chichester.

Phelps, D.G. & Bosch, O.J.H. (2002) A quantitative state and transition model for the mitchell grasslands of central western Queensland. *Ranglelan* **24**, 242-67.

Phelps, D., Lynes, B.C., Connelly, P.T., Horrocks, D.J., Fraser, G.W. & Jeffery, M.R. (2007) Sustainable grazing in the channel country floodplains (phase 2). Report to Meat & Livestock Australia, North Sydney.

Pickard, J. (1994) Post-European changes in creeks of semi-arid rangelands, Polpah Station, New South Wales. In: *Environmental Change in Drylands: Biogeographical and geomorphological perspectives* (Eds A.C. Millington and K. Pye), pp. 271-84. John Wiley & Sons, Chichester.

Pickup, G. (1989) New land degradation survey techniques for arid Australia - problems and prospects. *Rangeland Journal* **11**, 74-82.

Pieri, L., Bittelli, M. & Pisa, P.R. (2006) Laser diffraction, transmission electron microscopy and image analysis to evaluate a bimodal Gaussian model for particle size distribution in soils. *Geoderma* **135**, 118-32.

Pineiro, J.C. & Bates, D.M. (2004) *Mixed effects models in S and S-plus*. Springer, New York.

Ponder, W.F. (2003) Endemic aquatic macroinvertebrates of artesian springs of the Great Artesian Basin- progress and future directions. *Records of the South Australian Museum Monograph Series* **7**, 101-10.

Ponder, W.F., Carter, G.A., Flemons, P., Chapman, R.R. (2001) Evaluation of museum collection data for use in biodiversity assessment. *Conservation Biology* **15**, 648-657.

Ponder, W.F. & Slatyer, C (2007) Freshwater molluscs in the Australian arid zone. In *Animals of arid Australia: out on their own?* (Eds C. Dickman, D. Lunney & S. Burgin), pp. 1-13. Royal Zoological Society of New South Wales, Mosman.

Poot, P. & Lambers, H. (2003) Are trade-offs in allocation pattern and root morphology related to species abundance? A congeneric comparison between rare and common species in the south-western Australian flora. *Journal of Ecology*, **91**, 58–67.

Poot, P. & Lambers, H. (2008) Shallow-soil endemics: adaptive advantages and constraints of a specialized root-system morphology. *New Phytologist*, **178**, 371–381.

Popay, I. & Field, R. (1996) Grazing animals as weed control agents. *Weed Technology* **10**, 217-31.

Pople, A.R. & Grigg, G. (2001) Commercial Harvesting of Kangaroo in Australia. Environment Australia, Canberra

Pople, A.R. & Froese, J. (2012) Distribution, abundance and harvesting of feral goats in the Australian rangelands, 1984-2011. Final report to the ACRIS Management Committee. Queensland Department of Employment, Economic Development and Innovation, Brisbane.

Porembski, S. & Barthlott, W. (2000) Granitic and gneissic outcrops (inselbergs) as centers of diversity for desiccation-tolerant vascular plants. *Plant Ecology*, **151**, 19–28.

Porembski, S., Martinelli, G., Ohlemüller, R. & Barthlott, W. (1998) Diversity and ecology of saxicolous vegetation mats on inselbergs in the Brazilian Atlantic rainforest. *Diversity and Distributions*, **4**, 107–119.

Porter, J.L., Kingsford, R.T. & Brock, M.A. (2007) Seed banks in arid wetlands with contrasting flooding, salinity and turbidity regimes. *Plant Ecology* **188**, 215-234.

Possingham, H.P., Andelman, S.J., Burgman, M.A., Medellin, R.A., Master, L.L., Keith, D.A. (2002) Limits to the use of threatened species lists. *Trends in Ecology & Evolution* **17**, 503-507.

Powell, O.C., Silcock, J.L. & Fensham, R.J. (2013) Oases to oblivion: the rapid demise of springs in the south-eastern Great Artesian Basin, Australia. *Groundwater* Published online 18 December 2013, DOI: 10.1111/gwat.12147.

Preece, L.D., Duguid, A.W. & Albrecht, D.E. (2007) Environmental determinants of a restricted cycad in central Australia, *Macrozamia macdonnellii*. *Australian Journal of Botany* **55**, 601-607.

Preece, N. (2002) Aboriginal fires in monsoonal Australia from historical accounts. *Journal of Biogeography* **29**, 321-336.

Prendergast, J.R., Quinn, R.M., Lawton, J.H., Eversham, B.C. & Gibbons, D.W. (1993) Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* **365**, 335-337.

Preston, F.W. (1948) The commonness, and rarity, of species. *Ecology* **29**, 254-283.

Pringle, H.J.R. & Landsberg, J. (2004) Predicting the distribution of livestock grazing pressure in rangelands. *Austral Ecology* **29**, 31-9.

Prowse, T.A.A., Johnson, C.N., Bradshaw, C.J.A. & Brook, B.W. (2014) An ecological regime shift resulting from disrupted predator-prey interactions in Holocene Australia. *Ecology* **95**, 693-702.

Purdie, R. (1984) *Land Systems of the Simpson Desert Region*. Institute of Biological Resources, CSIRO, Canberra.

Pyatt, F.B., Grattan, J.P., Barker, G. & Mattingly, D. (1999) King Solomon's miners – starvation and bioaccumulation? An environmental archaeological investigation in southern Jordan. *Ecotoxicology and Environmental Safety* **43**, 305-8.

Qadir, M. & Schubert, S. (2002) Degradation processes and nutrient constraints in sodic soils. *Land Degradation and Development* **13**, 275-94.

Queeensland Parks & Wildlife Service and Environment Australia (1999) Rare and Rhreatened Species and Plant Communities of the Mulga Lands. Environmental Protection Agency, Brisbane.

Queensland Department of Environment and Resource Management (DERM) (2010) Changes and new additions to Queenslands' wildlife categories. Available at http://www.derm.qld.gov.au/wildlife/threatened_plants_and_animals/category_changes [ccessed 20 September 2010)]

R Development Core Team (2010) *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Rabinowitz, D. (1981) Seven forms of rarity. In *The Biological Aspects of Rare Plant Conservation* (Ed. H. Synge), pp. 205-217., John Wiley and Sons, Chichester.

Rabinowitz, D., Cairns, S. & Dillon, T. (1986) Seven forms of rarity and their frequency in the flora of the British Isles. In *Conservation Biology: the science of scarcity and diversity* (Ed. M.E. Soulé), pp. 182-204. Sinauer Associates, Massachusetts.

Ratcliffe, F.N. (1938) *Flying Fox and Drifting Sand: the adventures of a biologist in Australia*. Chatto & Windus, London.

Ravi, S., D'Odorico, P., Collins, S.L. & Huxman, T.E. (2009) Can biological invasions induce desertification? *New Phytologist* **181**, 512-5.

Read, J.L. (1999) The initial response of a chenopod shrubland plant and invertebrate community to two pulses of intensive cattle grazing. *The Rangeland Journal* **21**, 169-93.

Read, J.L. (2004) Catastrophic drought-induced die-off of perennial chenopod shrubs in arid Australia following intensive cattle browsing. *Journal of Arid Environments* **58**, 535-44.

Reid, J. & Fleming, P. (1992) The conservation status of birds in arid Australia. *Rangeland Journal* **14**, 65-91.

Reid, R.S. & Ellis, J.E. (1995) Impacts of pastoralists on woodlands in South Turkana, Kenya - livestock-mediated tree recruitment. *Ecological Applications* **5**, 978-92.

Rengasany, P. & Olsson, K.A. (1991) Sodicity and soil structure. *Australian Journal of Soil Research* **29**, 935-52.

Retzer, V. (2006) Impacts of grazing and rainfall variability on the dynamics of a Sahelian rangeland revisited (Hein, 2006) – new insights from old data'. *Journal of Arid Environments* **67**, 157-64.

Reveal, J.L. (1981) The concepts of rarity and population threats in plant communities. In: *Rare Plant Conservation: Geographical data organisation* (Eds L.E. Morse & M.S. Henifen), pp. 41-47, The New York Botanical Garden, Bronx.

Reynolds, J.A. & Carter, J.O. (1993) What Landholders Reckon About Woody Weeds in Central Western Queensland. Queensland Deparrtment of Primary Industries, Brisbane.

Reynolds, J. F., Grainger, A., Stafford Smith D. M., Bastin, G., Garcia-Barrios, L., Fernandez, R.J., Janssen, M.A., Jurgens, N., Scholes, R.J., Veldkamp, A., Verstraete, M.M., Von Maltitz, G. & Zdruli, P. (2011) Scientific concepts for an integrated analysis of desertification. *Land Degradation & Development* **22**, 166-83.

Reynolds, J.F., Stafford Smith, D.M., Lambin, E.F., Turner, B.L., Mortimore, M.., Batterbury, S.P.J., Downing, T.E., Dowlatabadi, H.., Fernández, R.J., Herrick, J.E., Huber-Sannwald, E., Jiang, H., Leemans, R., Lynam, T., Maestre, F.T., Ayarza, M. & Walker B. (2007) Global desertification: building a science for dryland development. *Science* **316**, 847-51.

Rietkerk, M., van den Bosch, F. & van de Koppel, J. (1997) Site-specific properties and irreversible vegetation changes in semi-arid grazing systems. *Oikos* **80**, 241-52.

Rivers, M.C., Taylor, L., Brummitt, N.A., Meagher, T.R., Roberts, D.L., Lughadha, E.N. (2011) How many herbarium specimens are needed to detect threatened species? *Biological Conservation* **144**, 2541-2547.

Robertson, A.I. & Rowling, R.W. (2000) Effects of livestock on riparian zone vegetation in an Australian dryland river. *Regulated Rivers: Research & Management* **16**, 527-541.

Rodd, F. (1938) The Sahara. *Geographical Journal* **91**, 354-5.

Rohner, C. & Ward, D. (1999) Large mammalian herbivores and the conservation of arid Acacia stands in the Middle East. *Conservation Biology* **13**, 1162-71.

Rolls, E.C. (1999) Land of grass: the loss of Australia's grasslands. *Australian Geographical Studies* **37**, 197-213.

Roques, K.G., O'Connor, T.G. & Watkinson, A.R. (2001) Dynamics of shrub encroachment in an African savanna: relative influences of fire, herbivory, rainfall and density dependence. *Journal of Applied Ecology* **38**, 268-80.

Rule, S., Brook, B.W., Haberle, S.G., Turney, C.S.M., Kershaw, A.P. & Johnson, C.N. (2012) The aftermath of megafaunal extinction: ecosystem transformation in Pleistocene Australia. *Science* **335**, 1483-6.

Russell, B.G., Letnic, M. & Fleming, P.J.S. (2011) Managing feral goat impacts by manipulating their access to water in the rangelands. *Rangeland Journal* **33**, 143-52.

Russell-Smith, J., Yates, C.E., A. , Allan, G.E., Cook, G.D., Cooke, P., Craig, R., Heath, B. & Smith, R. (2003) Contemporary fire regimes of northern Australia: change since Aboriginal occupancy, challenges for sustainable management. International *Journal of Wildland Fire* **12**, 283-297.

Ryan, D.G., Ryan, J.E. & Starr, B.J. (1995) The Australian Landscape: observations of explorers and early settlers. Murrumbidgee Catchment Management Committee, Wagga Wagga, New South Wales.

Ryerson, D.E. & Parmenter, R.R. (2001) Vegetation change following removal of keystone herbivores from desert grasslands in New Mexico. *Journal of Vegetation Science* **12**, 167-80.

Saalfeld, W.K. & Edwards, G.P. (2010) Distribution and abundance of the feral camel (*Camelus dromedarius*) in Australia. *Rangeland Journal* **32**, 1-9.

Saleh, M.A. (1987) The decline of gazelles in Egypt. *Biological Conservation* **39**, 83-95.

Sandell, P.R. & Start, A.N. (1999) Rabbit Calicivirus Disease Program Report 4: Implications for Biodiversity in Australia. Prepared for the Rabbit Calicivirus Disease Management Group. Bureau of Rural Sciences, Canberra.

Scanlan, J.C., Berman, D.M. & Grant, W.E. (2006) Population dynamics of the European rabbit (*Oryctolagus cuniculus*) in north eastern Australia: simulated responses to control. *Ecological Modelling* **196**, 221-36.

Scanlan, J.C. & Presland, A.J. (1984) Major Woody Weeds of Western Queensland and Their Control. Information Series Q184017. Queensland Department of Primary Industries, Brisbane.

Schubert, S.D., Suarez, M.J., Pegion, P.J., Koster, R.D. & Bachmeister, J.T. (2004) On the cause of the 1930s Dust Bowl *Science* **303**, 1855-9.

Seymour, C.L., Milton, S.J., Joseph, G.S., Dean, W.R.J., Ditlhobolo, T. & Cumming, G.S. (2010) Twenty years of rest returns grazing potential, but not palatable perennial plant diversity, to Karoo rangeland, South Africa. *Journal of Applied Ecology* **47**, 859-67.

Sharp, D. & Simon, B.K. (2002) AusGrass: grasses of Australia (electronic resource), Australian Biological Resources Study, Canberra.

Shaw, R., Brebber, L., Ahern, C. & Weinand, M. (1994) A review of sodicity and sodic soil behaviour in Queensland. *Australian Journal of Soil Research* **32**, 143-72.

Shearer, B.L., Crane, C.E., Barnett, S. & Cochrowe, A. (2007) *Phytophtohora cinnamoni* invasion, a major threatening process to conservation of flora diversity in the South-West Botanical Province of Western Australia. *Australian Journal of Botany* **55**, 225-238.

Shrader, A.M., Brown, J.S., Kerley, G.I.H. & Kotler, B.P. (2008) Do free-ranging domestic goats show 'landscapes of fear'? Patch use in response to habitat features and predator cues. *Journal of Arid Environments*, **72**, 1811–1819.

Silcock, J. (2009) Identification of Permanent Refuge Waterbodies in the Cooper Creek & Georgina-Diamantina catchments. South Australia Arid Lands Natural Resource Management Board, available online at http://www.saalnrm.sa.gov.au/Portals/8/Publications_Resources/Project_Reports [accessed 13 July 2011].

Silcock, J.L. & Fensham, R.J. (2013) Arid vegetation in disequilibrium with livestock grazing: evidence from long-term exclosures. *Austral Ecology* **38**, 57-65.

Silcock, J.L., Fensham, R.J. & Martin, T.G. (2011) Assessing rarity and threat in an arid-zone flora. *Australian Journal of Botany* **59**, 336-350.

Silcock, J.L., Powell, O.C., Drimer, J. & Fensham, R.J. (2014) Part I - Cultural history and ecological values of Great Artesian Basin springs in the Springsure, Eulo, Bourke and Bogan River supergroups. Final Report for Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Simmons, A. (2007) "Life in a Corridor": An archaeological investigation of the Diamantina Channel Country - a western Queensland corridor. PhD Thesis, University of Queensland, St Lucia.

Sinclair, A.R.E. & Fryxell, J.M. (1985) The Sahel of Africa: ecology of a disaster. *Canadian Journal of Zoology* **63**, 987-94.

Sinclair, T.R. & Sinclair, C.J. (2010) *Bread, Beer and the Seeds of Change: Agriculture's Imprint on World History*. CABI, Wallingford, UK.

Singh, K.N., Lal, B., Singh, R.D., Todaria, N.P. & Ahuja, P.S. (2007) Species richness, distribution pattern and conservation status of higher plants in the Spiti cold desert of trans-Himalaya India. *International Journal of Biodiversity Science and Management* **3**, 223-233.

Slimani, H., Aidoud, A. & Roze, F. (2010) 30 Years of protection and monitoring of a steppic rangeland undergoing desertification. *Journal of Arid Environments* **74**, 685-91.

Smith, M.A. (2013) *The Archaeology of Australian Deserts*. Cambridge University Press, Cambridge.

Smith, P.J., Pressey, R.L. & Smith J. E. (1994) Birds of particular conservation concern in the Western Division of New South Wales. *Biological Conservation* **69**, 315-38.

Smyth, A., Friedel, M. & O'Malley, C. (2009) The influence of buffel grass (*Cenchrus ciliaris*) on biodiverstiy in an arid Australian landscape. *The Rangleand Journal* **31**, 307-20.

Soliveres, S. & Eldridge, D.J. (2014) Do changes in grazing pressure and the degree of shrub encroachment alter the effects of individual shrubs on understorey plant communities and soil function? *Functional Ecology* **28**, 530-7.

Solow, A.R. (2005) Inferring extinction from a sighting record. *Mathematical Biosciences* **195**, 47-55.

Southwell, C., Weaver, K., Sheppard, N. & Morris, P. (1993) Distribution and relative abundance of feral goats in the rangelands of eastern Australia. *Rangeland Journal* **15**, 331-3.

Specht, R.L., Roe, E.M. & Broughton, V.H., 1974. Conservation of Major Plant Communities in Australia and Papua New Guinea. *Australian Journal of Botany* Supplement No. 7.

Spies, P. & March, N. (2004) Prickly acacia. National Case Studies Manual, Department of Natural Resources, Mines and Energy, Brisbane.

Sprugel, D.G. (1991) Disturbance, equilibrium, and environmental variability - what is natural vegetation in a changing environment? *Biological Conservation* **58**, 1-18.

Stebbing, E.P. (1935) The encroaching Sahara: the threat to the West Africa colonies. *Geographical Journal* **85**, 506-24.

Stebbing, E.P. (1938) The advance of the Sahara. *Geographical Journal* **91**, 356-9.

Steinbeck, J. (1939) *The Grapes of Wrath*. Heinemann, Melbourne.

Stern, M.J. & Eriksson, T. (1996) Symbioses in herbaria: Recommendations for more positive interactions between plant systematists and ecologists. *Taxon* **45**, 49-58.

Stohlgren, T.J., Guenther, D,A,, Evangelista, P.H. & Alley, N. (2005) Patterns of plant species richness, rarity, endemism, and uniqueness in an arid landscape. *Ecological Applications* **15**, 715-25.

Stoner, D.C., Wolfe, M.L., Rieth, W.R., Bunnell, K.D., Durham, S.L. & Stoner, L.L. (2013) De facto refugia, ecological traps and the biogeography of anthropogenic cougar mortality in Utah. *Diversity and Distributions* **19**, 1114-24.

Stow, R. (1963) *Tourmaline*. Angus & Robertson, Sydney.

Strahan, R. (Ed.) (2004) *The Mammals of Australia*. Reed New Holland, Sydney.

Struver, F. (1890) *Our Stock and Pastures*. Warwick and Sapsford, Brisbane.

Sullivan, S. & Rohde, R. (2002) On non-equilibrium in arid and semi-arid grazing systems. *Journal of Biogeography* **29**, 1595-618.

Sullivan, S. (1999) The impacts of people and livestock on topographically diverse open wood- and shrub-lands in arid north-west Namibia. *Global Ecology and Biogeography* **8**, 257-77.

Swetnam, T.W., Allen, C.D. & Betancourt, J. (1999) Applied historical ecology: using the past to manage for the future. *Ecological Applications* **9**, 1189-1206.

Swift, J. (1996) Desertification: narratives, winners and losers. In: *The Lie of the Land: Challenging received wisdom on the African environment* (Eds M. Leach & R. Mearns), The International African Institute, London.

Tegen, I., Werner, M., Harrison, S.P. & Kohfled, K.E. (2004) Relative importance of climate and land use in determining present and future global soil dust emissions. *Geophysical Science Review* **1004**, L05105.

Tewari, V.P. & Arya, R. (2004) Degradation of arid rangelands in Thar Desert, India: a review. *Arid Land Research and Management* **19**, 1-12.

Thackway, R. & Cresswell, I.D. (Eds) (1995) An interim biogeographic regionalisation for Australia: a framework for establishing a national system of reserves, version 4.0. Australian Nature Conservation Agency, Canberra. [Current version 6.1, available online at http://www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/index.html]

Thiollay, J.M. (2006) Severe decline of large birds in the Northern Sahel of West Africa: a long term assessment. *Bird Conservation International* **16**, 353–65.

Thomas, D.A., Squires, V.R., Buddee, W. & Turner J. (1986) Rangeland regeneration in the steppic regions of the Mediterranean basin. In: *Rangelands: A Resource Under Siege* (Ed P. L. Joss). Cambridge University Press, Cambridge.

Thomas, D.S.G. & Middleton, N. (1994) *Desertification: Exploding the Myth*. John Wiley & Sons Ltd, West Sussex.

Thomas, D.S.G. (1997) Science and the desertification debate. *Journal of Arid Environments* **37**, 599–608.

Tiver, F. & Andrew, M.H. (1997) Relative effects of herbivory by sheep, rabbits, goats and kangaroos on recruitment and regeneration of shrubs and trees in eastern South Australia. *Journal of Applied Ecology* **34**, 903-14.

Tobler, M., Honorio, E., Janovec, J. & Reynel, C. (2007) Implications of collection patterns of botanical specimens on their usefulness for conservation planning: an example of two neotropical plant families (Moraceae and Myristicaceae) in Peru. *Biodiversity and Conservation* **16**, 659-677.

Tolcher, H.M. (1986) *Drought or Deluge: Man in the Cooper's Creek Region*. Melbourne University Press, Carlton.

Tongway, D.J. & Ludwig, J.A. (1990) Vegetation and soil patterning in semi-arid mulga lands of Eastern Australia. *Australian Journal of Ecology* **15**, 23-34.

Tongway, D.J., Sparrow, A.D. & Friedel, M.H. (2003) Degradation and recovery processes in arid grazing lands of central Australia. Part 1: Soil and land resources. *Journal of Arid Environments* **55**, 301-26.

Tucker, C.J., Dregne, H.E. & Newcomb, W.W. (1991) Expansion and contraction of the Sahara desert from 1980 to 1990. *Science* **253**, 299–301.

Turnbull, L.A., Crawley, M.J. & Rees, M. (2000) Are plant populations seed-limited? A review of seed sowing experiments. *Oikos*, **88**, 225–238.

Turner, E.J., McDonald, W.J.F., Ahern, C.R. & Thomas, M.B. (1993) Western Arid Region Land Use Study – Part V. Technical Bulletin No.30., Division of Land Utilisation, Queensland Department of Primary Industries, Brisbane.

Turner, M.D. (1999) Spatial and temporal scaling of grazing impact on the species composition and productivity of Sahelian annual grasslands. *Journal of Arid Environments* **41**, 277-97.

UNCCD (2014) *Desertification: the invisible frontline*. United Nations Convention to Combat Desertification, Bonn, Germany.

UNEP (2011) Coordinating global action to combat desertification. Online at http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=664&ArticleID=6918&l=en&t=long. United Nations Environment Program, Bonn/Nairobi.

Valone, T.J., Meer, M., Brown, J.H. & Chew, R.M. (2002) Timescale of perennial grass recovery in desertified arid grasslands following livestock removal. *Conservation Biology* **16**, 995-1002.

Van Auken, O.W. (2000) Shrub invasions of north American semiarid grasslands. *Annual Review of Ecology and Systematics* **31**, 197-215.

Van de Koppel, J., Rietkerk, M., van Langevelde, F., Kumar, L., Klausmeier, C. A., Fryxell, J.M., Hearne, J.W., van Andel, J., de Ridder, N., Skidmore, A., Stroosnijder, L. & Prins, H.H.T. (2002) Spatial heterogeneity and irreversible vegetation change in semiarid grazing systems. *American Naturalist* **159**, 209-18.

Van de Koppel, J., Rietkerk, M. & Weissing, F.J. (1997) Catastrophic vegetation shifts and soil degradation in terrestrial grazing systems. *Trends in Ecology and Evolution* **12**, 352-6.

Van der Veken, S., Bellemare, J., Verheyen, K. & Hermy, M. (2007) Life-history traits are correlated with geographical distribution patterns of western European forest herb species. *Journal of Biogeography*, **34**, 1723–1735.

Van Etten E.J.B. (2009) Inter-annual rainfall variability of arid Australia: greater than elsewhere? *Australian Geographer* **40**, 109-20.

Verón, S.R., Paruelo, J.M. & Oesterheld M. (2006) Assessing desertification. *Journal of Arid Environments* **66**, 751-63.

Verstraete, M.M. (1986) Defining desertification - a review. *Climatic Change* **9**, 5-18.

Verstraete, M.M., Scholes, R.J. & Smith M.S. (2009) Climate and desertification: looking at an old problem through new lenses. *Frontiers in Ecology and the Environment* **7**, 421-8.

Veth, P.M. & Walsh, F.J. (1988) The concept of ’staple’ plant foods in the Western Desert region of Western Australia. *Australian Aboriginal Studies* **2**, 19-26.

Veth, P.M. (1993) *Islands in the Interior: the dynamics of prehistoric adaptations within the arid zone of Australia*. International Monographs in Prehistory, Michigan.

Vetter, S. (2005) Rangelands at equilibrium and non-equilibrium: recent developments in the debate. *Journal of Arid Environments* **62**, 322-41.

Vigilante, T. (2001) Analysis of explorer's records of aboriginal landscape burning in the Kimberley region of Western Australia. *Australian Geographical Studies* **39**, 135-155.

Walck, J.L., Baskin, J.M. & Baskin, C.C. (1999) Relative competitive abilities and growth characteristics of a narrowly endemic and a geographically widespread *Solidago* species (Asteraceae). *American Journal of Botany*, **86**, 820–828.

Waldram, M.S., Bond, W.J. & Stock, W.D. (2008) Ecological engineering by a mega-grazer: White Rhino impacts on a South African savanna. *Ecosystems* **11**, 101-12.

Walker, J., Condon R.W., Hodgkinson, K.C. & Harrington, G.N. (1981) Fire in pastoral areas of poplar box (*Eucalyptus populnea*) lands. *Australian Rangeland Journal* **3**, 12-23.

Walker, S. & Wilson, J.B. (2002) Tests for nonequilibrium, instability, and stabilising processes in semiarid plant communities. *Ecology* **83**, 809-22.

Walker, F. (1863) Journal of an Expedition in Search of Burke and Wills. *Journal of Royal Geographical Society* **33**, 133-150.

Walsh, F.J. (1990) An ecological study of traditional Aboriginal use of “country”: Martu in the Great and Little Sandy Deserts, Western Australia. *Proceedings of the Ecological Society of Australia* **16**.

Wang, X.M., Chen, F., Hasi, E. & Li J.C. (2008) Desertification in China: An assessment. *Earth-Science Reviews* **88**, 188-206.

Ward, D., Ngairorue, B.T., Kathena, J., Samuels, K. & Ofran, Y. (1998) Land degradation is not a necessary outcome of communal pastoralism in arid Namibia. *Journal of Arid Environments* **40**, 357-71.

Ware, S. (1990) Adaptation to substrate – and lack of it – in rock outcrop plants: *Sedum* and *Arenaria*. *American Journal of Botany*, **77**, 1095–1100.

Watson, G.C. (1882) The Gregory South and Warrego Districts (Mr. Watson’s report on the physical features of the country). A four page submission with accompanying map presented to both Houses of Parliament, Queensland 28th November, 1881. Queensland Government Printer, Brisbane.

Watson, I.W., Burnside, D.G. & Holm, A.M. (1996) Event-driven or continuous: which is the better model for managers? *Rangeland Journal* **18**, 351-69.

Watson, I.W., Westoby, M. & Holm, A.M. (1997) Demography of two shrub species from an arid grazed ecosystem in Western Australia 1983-93. *Journal of Ecology* **85**, 815-32.

Wei, Y., Bai, Y. & Henderson, D.C. (2009) Critical conditions for successful regeneration of an endangered annual plant, *Cryptantha minima*: a modelling approach. *Journal of Arid Environments* **73**, 872-875.

Welsh, F. (2004) *Great Southern Land: a new history of Australia*. Penguin Books, London.

Wessels, K.J., Prince, S.D., Carrol, M. & Malherbe, J. (2007) Relevance of rangeland degradation in semiarid northeastern South Africa to the nonequilibrium theory. *Ecological Applications* **17**, 815-27.

Westbrooke, M.E. & Florentine, S.K. (2005) Rainfall-driven episodic flood events: are they are a major factor in moulding New South Wales arid land vegetation patterns? *Australian Geographer* **36**, 171-181.

Westoby, M., Walker, B. & Noy-Meir, I. (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Rangeland Management* **42**, 266-74.

White, M. E. (1997) *Listen…our land is crying – Australia's environment: problems and solutions*. Kangaroo Press, Sydney.

Whitehouse, F.W. (1940) Studies in the late geological history of Queensland. University of Queensland Papers (Department of Geology), Vol. 2. University of Queensland, St Lucia, Queensland.

Wiegand, T. & Jeltsch, F. (2000) Long-term dynamics in arid and semiarid ecosystems – synthesis of a workshop. *Plant Ecology* **150**, 3-6.

Wilcox, B.P. & Huang, Y. (2010) Woody plant encroachment paradox: Rivers rebound as degraded grasslands convert to woodlands. *Geophysical Research Letters* **37**.

Wild, M. & Gagnon, D. (2005) Does lack of available suitable habitat explain the patchy distributions of rare calcicole fern species? *Ecography*, **28**, 191–196.

Williams, O.B. (1981) Monitoring changes in populations of desert plants, In: *The Biological Aspects of Rare Plant Conservation* (Ed. H. Synge), pp. 233-240. John Wiley and Sons, Chichester.

Williams, O.B. & Mackey, B. (1983) Easy-care, no-hassle conservation - Mitchell grass (*Astrebla*). A case study from the South Oestrus exclosure, Gilruth Plains, Cunnamulla, Queensland. In: *What Future for Australia's Arid Lands* (Eds J. Messer and G. Mosley), pp. 141-145. Australia Conservation Foundation, Melbourne.

Williams, P.R. (2006) Determining the management requirements of threatened plant species. *Ecological Management and Restoration* **7**, 148-151.

Williams, W.J., Eldridge, D.J. & Alchin, B.M. (2008) Grazing and drought reduce cyanobacterial soil crusts in an Australian *Acacia* woodland. *Journal of Arid Environments* **72**, 1064-75.

Willis, F., Moat, J. & Paton, A. (2003) Defining a role for herbarium data in Red List assessments: a case study of Plectrantus from eastern and southern tropical Africa. *Biodiversity and Conservation* **12**, 1537-1552.

Wilson, A.D. & Mulham, W.E. (1979) A survey of the regeneration of some problem shrubs and trees after wildfire in western New South Wales. *Australian Rangeland Journal* **1**, 363-8.

Wilson, A.D., Mulham, W.E. & Leigh, J.H. (1976) A note on the effects of browsing by feral goats on a belah (*Casuarina cristata*) - rosewood (*Heterodendrum oleifolium*) woodland. *Australian Rangeland Journal* **1**, 7-12.

Wilson, G. & Knight, A.L.L. (2004) Increasing the numbers of wildlife preferred by Aboriginal communities in the Anangu Pitjantjatjara Lands, Australia. *Game and Wildlife Science* **21**, 687-95.

Wilson, P.R., Purdie, R.W. & Ahern, C.R. (1990) Western Arid Region Land Use Study – Part VI. Technical Bulletin 28. Division of Land Utilisation, Queensland Department of Primary Industries, Brisbane.

Wilson, S. & Swan, G. (2010) *A Complete Guide to Reptiles of Australia*. New Holland, Sydney.

Winnecke, C. (1884) Mr. Winnecke's explorations during 1883, South Australian Parliamentary Papers 39, Adelaide.

Wiser, S.K., Peet, R.K. & White, P.S. (1996) High-elevation rock outcrop vegetation of the Southern Appalachian Mountains. *Journal of Vegetation Science*, **7**, 703–722.

Witt, G.B. (2013) Vegetation changes through the eyes of the locals: the 'artificial wilderness' in the mulga country of south-west Queensland. *Rangeland Journal* **35**, 299-314.

Witt, G.B. & Beeton, R.J.S. (1995) The regional implications of "naturalness" in protected area management: a case study from the Queensland mulgalands. In: *Ecological Research and Management in the Mulga Lands - Conference Proceedings* (Eds M.J. Page & T.S. Beutel). University of Queensland, Gatton.

Witt, G.B., Berghammer, L.J., Beeton, R.J.S. & Moll, E.J. (2000) Retrospective monitoring of rangeland vegetation change: ecohistory from deposits of sheep dung associated with shearing sheds. *Austral Ecology* **25**, 260-7.

Witt, G.B., Harrington, R.A. & Page, M.J. (2009) Is 'vegetation thickening' occurring in Queensland's mulga lands - a 50-year aerial photographic analysis. *Australian Journal of Botany* **57**, 572-82.

Witt, G.B., Luly, J. & Fairfax, R.J. (2006) How the west was once: vegetation change in south-west Queensland from 1930-1995. *Journal Biogeography* **33**, 1585-96.

Witt, G.B., Moll, E.J. & Beeton, R.J.S. (1997) Sheep faeces under shearing sheds: a documentary of vegetation change using stable carbon isotope analysis. *Rangeland Journal* **19**, 109-15.

Woinarski, J.C.Z., Burbidge, A.A. & Harrison, P. (2014) *The Action Plan for Australian Mammals 2012*. CSIRO Publishing, Collingwood.

Woinarski, J.C.Z & Fisher, A. (2003) Conservation and the maintenance of biodiversity in the rangelands. *Rangeland Journal* **25**, 157-171.

Woinarski, J.C.Z. & Legge, S. (2013) The impacts of fire on birds in Australia's tropical savannas. *Emu* **113**, 319-52.

Woolley, A, & Kirkpatrick, J.B. (1999) Factors related to condition and rare and threatened species occurrence in lowland, humid basalt remnants in northern Tasmania. *Biological Conservation* **87**, 131-142.

Worster, D. (1979) *Dust Bowl: The Southern Plains in the 1930s*. Oxford University Press, New York.

Yates, C., Gibson, N., Pettit, N.E., Dillon, R. & Palmer, R. (2011) The ecological relationships and demography of restricted ironstone endemic plant species: implications for conservation. *Australian Journal of Botany* **59**, 692-700.

Yates, C.J., Ladd, P.G., Coates, D.J. & McArthur, S. (2007) Hierarchies of cause: understanding rarity in an endemic shrub *Verticordia staminosa* (Myrtaceae) with a highly restricted distribution. *Australian Journal of Botany*, **55**, 194–205.

Youlin, Y., Squires, V. & Qi, L. (2001) *Global Alarm: dust and sandstorms from the world's drylands*. United Nations. Available online at: http://www.unccd.int/en/resources/publication/Pages/default.aspx?HighlightID=300 [accessed 15 January 2014].

Zhang, J.Y., Wang, Y., Xia, Z., Xie, G. & Zhang, T. (2005) Grassland recovery by protection from grazing in a semi-arid sandy region of northern China. *New Zealand Journal of Agricultural Research* **48**, 277-84.

Zhang, Y-B & Ma K-P (2008) Geographic distribution patterns and status assessment of threatened plants in China. *Biodiversity and Conservation* **17**, 1783-1798.

Appendices

Appendix 1-1.

Fensham, R.J., Silcock, J.L. & Dwyer, J.M. 2011, 'Plant species richness responses to grazing protection and degradation history in a low productivity landscape', *Journal of Vegetation Science* 22: 997-1008 [ABSTRACT ONLY].

Questions: Does species richness and abundance accumulate with grazing protection in low productivity ecosystems with a short evolutionary history of grazing, as predicted by emerging theory? How do responses to grazing protection inform degradation history?

Location: Mulga (*Acacia aneura*) dry forest in eastern Australia, generally thought to be chronically degraded by livestock grazing.

Methods: Three paired exclosures (ungrazed, and macropod-grazed) were compared with open-grazed areas after 25 years using quadrats located on either side of the fences. Additionally, the regional flora for mulga dry forest was assessed to identify species that may have declined and could be threatened by grazing.

Results: Low herbaceous biomass accumulation (<1.3 $t.ha^{-1}$) with full grazing protection confirmed a low productivity environment. For most plant life-forms the highest species richness was in the macropod-grazed exclosures, an intermediate grazing disturbance that best approximates the evolutionary history of the environment. This result was the net outcome of species that both declined and increased in response to grazing. Regeneration and subsequent self-thinning of mulga was promoted with grazing protection, but did not confound the interpretation of species richness and abundance responses. At the regional scale only eleven native species out of 407 comprising the mulga dry forest flora were identified as rare and potentially threatened by grazing.

Conclusions: Significant increases in richness or abundance of native plants with grazing protection, persistence of perennial grasses, regeneration of mulga and scant evidence of a major decline in the regional flora are not consistent with established assertions that long-grazed mulga dry forest has crossed functional thresholds that limit recovery. Further, a peak in species richness under intermediate (macropod) grazing is counter to the shape of the response predicted by emerging theory for recovery of species richness in a low productivity environment. The finding prompts a more thorough understanding of the distinction between environments with inherently low productivity and those degraded by grazing.

Appendix 1-2.

Fensham, R.J., Silcock J.L. & Firn, J. 2014, 'Managed livestock grazing is compatible with the maintenance of plant diversity in semi-desert grasslands', *Ecological Applications* 24: 503-17 [ABSTRACT ONLY].

Even when no baseline data are available, the impacts of 150 years of livestock grazing on natural grasslands can be assessed using a combined approach of grazing manipulation and regional-scale assessment of the flora. Here, we demonstrate the efficacy of this method across 18 sites in the semi-desert Mitchell grasslands of north-eastern Australia. Fifteen year old exclosures (ungrazed and macropod grazed) revealed that the dominant perennial grasses in the genus *Astrebla* do not respond negatively to grazing disturbance typical of commercial pastoralism. Neutral, positive, intermediate and negative responses to grazing disturbance were recorded amongst plant species with no single lifeform group associated with any response type. Only one exotic species, *Cenchrus ciliaris* was recorded at low frequency. The strongest negative response was from a native annual grass *Chionachne hubbardiana*, an example of a species that is highly sensitive to grazing disturbance. Herbarium records revealed only scant evidence that species with a negative response to grazing have declined through the period of commercial pastoralism. A regional analysis identified 14 from a total of 433 plant species in the regional flora that may be rare and potentially threatened by grazing disturbance. However, a targeted survey precluded grazing as a cause of decline for seven of these based on low palatability and positive responses to grazing and other disturbance. Our findings suggest that livestock grazing of semi-desert grasslands with a short evolutionary history of ungulate grazing has altered plant composition, but has not caused declines in the dominant perennial grasses or in species richness as predicted by the preceding literature. The biggest impact of commercial pastoralism is the spread of woody leguminous trees that can transform grassland to thorny shrubland. The conservation of plant biodiversity is largely compatible with commercial pastoralism provided these woody weeds are controlled, but reserves strategically positioned within water remote areas are necessary to protect grazing-sensitive species. This study demonstrates that a combination of experimental studies and regional surveys can be used to understand anthropogenic impacts on natural ecosystems where reference habitat is not available.

<u>Appendix 2-1.</u> Supporting and contradictory references for prevailing paradigms and hypotheses tested using explorer record

Prevailing paradigm	Supporting references	Contradictory references
There has been a general thickening of woody overstorey vegetation in the semi-arid zone of Queensland, especially *Acacia aneura* and *A.cambagei*	Anon. 1969; Anon. 1901; Beale 2004; Beale et al. 1986; Booth and Barker 1981; Burrows 1973, 2002; Burrows et al. 1997; Duyker 1983; Fensham and Fairfax 2005; Flannery 1994; Gammage 2011; Gasteen 1982; Krull et al. 2005; Ludwig and Tongway 1995; Mills 1986; Mills et al. 1989; Moore 1973; Moore et al. 2001; Noble 1997; Oxley 1987; Pressland 1975, 1984; Pressland and Graham 1989; Reynolds and Carter 1993; Reynolds et al. 1994; Reynolds et al. 1992; Rolls 1999; Scanlan and Presland 1984	Croft et al. 1997; Denny 1987; Fensham et al. 2011; Mitchell 1991; Witt et al. 2009; Witt et al. 2006
(i) Fires are less frequent across the semi-arid zone, especially the mulga forests and Mitchell grasslands, due to lower biomass and active suppression (ii) In spinifex-dominated ecosystems, small, regular 'patchy' fires have been replaced by large, destructive wildfires following good seasons	(i) Anon. 1901; Anon. 1969; Duyker 1983; Gammage 2011; Griffin & Hodgkinson 1986; Hodgkinson & Harrington 1985; Jones 1996; Reynolds & Carter 1993; Rolls 1984; Noble & Grice 2002. (ii) Allan & Southgate 2002; Greenville et al. 2009; Latz 2007	(i) Dawson et al. 1975; Fensham 1997; Hodgkinson 2002
Waterholes in some regions have 'silted up' since pastoral settlement due to the loss of groundcover and subsequent accelerated erosion, resulting in a decrease in depth and therefore permanence	Fanning 1999; Gale & Haworth 2005; Pickard 1994; Silcock 2009; Tolcher 1986	
The range and abundance of macropods have increased in semi-arid areas since pastoral settlement. Macropods were always abundant in wetter areas of eastern Australia prior to European settlement. Red kangaroo numbers fluctuate with seasons but have not changed greatly in the arid zone.	Auty 2004; Barker & Caughley 1993; Calaby & Grigg 1989; Caughley et al. 1977; Caughley et al. 1987; Dawson et al. 2006; Denny 1980; Denny 1987; Denny 1994; Fukada et al. 2009; Newsome 1975; Pople & Grigg 2001	
The range and abundance of medium-sized mammals have contracted across the study area	Denny 1994; Johnson 2006; Letnic 2000; Marshall 1966	

References

Allan, G.E., Southgate, R.I., 2002. Fire regimes in spinifex landscapes, in: Bradstock, R.A., Williams, J.E., Gill, M.A. (Eds.), Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge University Press, Cambridge, pp. 145-176.

Anon., 1901. Royal Commission of Inquiry into the Condition of the Crown Tenants, Western Division of New South Wales. Government Printer, Sydney.

Anon., 1969. Report to the Inter-departmental Committee on Scrub and Timber Regrowth in the Cobar-Byrock district and other areas of the Western Division of New South Wales. Goverment Printer, Sydney.

Auty, J., 2004. Red plague grey plague: the kangaroo myths and legends. Australian Mammology 26, 33-36.

Barker, R.D., Caughley, G., 1993. Distribution and abundance of kangaroos (Marsupialia: Macropodidae) at the time of European contact: South Australia. Australian Mammalogy 17, 73-83.

Beale, I., 2004. Tree and shrub thickening in the Murweh Shire. Report to the Productivity Commission, http://www.pc.gov.au/__data/assets/pdf_file/0008/49373/murweh3.pdf (accessed 16 April 2011).

Beale, I.F., Orr, D.M., Mills, J.R., 1986. Pastoral impacts on the mulga ecosystem, in: Sattler, P.S. (Ed.), The Mulga Lands. Royal Society of Queensland, Brisbane, pp.50-53.

Booth, C.A., Barker, P.J., 1981. Shrub invasion on sandplain country west of Wanaaring, New South Wales. Journal of Soil Conservation Service, New South Wales 37, 65-70.

Burrows, W.H., 1973. Regeneration and spatial patterns of *Acacia aneura* in south west Queensland. Tropical Grasslands 7, 57-68.

Burrows, W.H., 2002. Seeing the wood(land) for the trees – an individual perspective of Queensland woodland studies (1965-2002). Tropical Grasslands 36, 202-217.

Burrows, W.H., Anderson, E.R., Back, P.C., Hoffman, M., 1997. Regrowth and woody plant thickening/invasion: impacts on the land use change and forest inventory. IPCC Workshop on Biomass Burning, Land-Use Change and Forestry, Rockhampton.

Caughley, G., Sinclair, R.G., Wilson, G.R., 1977. Numbers, distribution and harvesting rate of kangaroos on the inland plains of New South Wales. Australian Wildlife Research 4, 99-108.

Caughley, G., Shepherd, N., Short, J., 1987. Kangaroos, Their Ecology and Management in the Sheep Rangelands of Australia. Cambridge University Press, Cambridge.

Calaby, J.H., Grigg, G.C., 1989. Changes in macropodoid communities and populations in the past 200 years, and the future, in: Grigg, G., Jarman, P., Hume, I. (Eds.), Kangaroos, Wallabies and Rat-Kangaroos. Surrey Beatty & Sons Pty Limited, Sydney, pp. 813-820.

Croft, M., Goldney, D., Cardale, S., 1997. Forest and woodland cover in the central western region of New South Wales prior to European settlement, in: Hale, P., Lamb, D. (Eds.), Conservation Outside Nature Reserves. Centre for Conservation Biology, University of Queensland, St Lucia, pp. 394-426.

Dawson, N.M., Boyland, D.E., Ahern, C.R., 1975. Land management in south-west Queensland. Proceedings of the Ecological Society of Australia 9, 124-141.

Dawson, T.J., McTavish, K.J, Munn, A.J., Holloway, J., 2006. Water use and the thermoregulatory behaviour of kangaroos in arid regions: insights into the colonisation of arid rangelands in Australia by the eastern grey kangaroo (*Macropus giganteus*). Journal of Comparative Physiology B 176, 45-53.

Denny, M.J.S., 1980. Red kangaroo arid zone studies. Australian National Parks and Wildlife Service, Canberra.

Denny, M.J.S., 1987. Historical and ecological study of the effects of European settlement on inland New South Wales. Nature Conservation Council of New South Wales, Sydney.

Denny, M.J.S., 1994. Investigating the past: an approach to determining the changes in the fauna of the Western Division of New South Wales since the first explorers, in: Lunney, D., Hand, S., Reed, P., Butcher, D. (Eds.), Future of the Fauna of Western New South Wales. Royal Zooological Society of New South Wales, Mosman, pp. 53-63.

Duyker, E., 1983. Land use and ecological change in central New South Wales. Journal of the Royal Australian Historical Society 69, 121-131.
Fanning, P., 1999. Recent landscape history in arid western New South Wales, Australia: a model for regional change. Geomorphology 29, 191-209.
Fensham, R.J., 1997. Aboriginal fire regimes in Queensland, Australia: analysis of the explorers' record. Journal of Biogeography 24, 11-22.
Fensham, R.J., Fairfax, R.J., 2005. Preliminary assessment of gidgee (*Acacia cambagei*) woodland thickening in the Longreach district, Queensland. The Rangeland Journal 27, 159-168.
Fensham, R.J., Powell, O., Horne, J., 2011. Rail survey plans to remote sensing: Vegetation change in the Mulga Lands of eastern Australia and its implications for land-use. The Rangeland Journal 33, 229-238.
Flannery, T., 1994. The Future Eaters. Reed Books, Melbourne.
Fukada, Y., McCallum, H.I., Grigg, G.C., Pople, A.R., 2009. Fencing artificial waterpoints failed to influence density and distribution of red kangaroo (*Macropus rufus*). Wildllife Research 36, 457-465.
Gale, S.J., Haworth, R.J., 2005. Catchment wide soil loss from pre-agricultural time to the present: transport-and supply-limitation of erosion. Geomorphology 68, 314-333.
Gammage, B., 2011. The Biggest Estate on Earth: how Aborigines made Australia. Allen & Unwin, Sydney.
Gasteen, W.J., 1982. Trends and condition of Queensland's arid and semi-arid lands, in: Messer, J., Mosley, G. (Eds.), What Future for Australia's Arid Lands? Australian Conservation Foundation, Melbourne, pp.152-155.
Greenville, A.C., Dickman, C.R., Wardle, G.M., Letnic, M., 2009. The fire history of an arid grassland: the influence of antecedant rainfall and ENSO. International Journal of Wildland Fire 18, 631-639.
Griffin, G.F., Hodgkinson, K.C., 1986. The use of fire for the management of the mulga land vegetation in Australia, in: Sattler, P.S. (Ed.), The Mulga Lands. Royal Society of Queensland, Brisbane, pp. 93-97.
Hodgkinson, K.C., Harrington, G.N., 1985. The case for prescribed burning to control shrubs in eastern semi-arid woodlands. Australian Rangeland Journal 7, 64-74.
Hodgkinson, K.C., 2002. Fire regimes in Acacia wooded landscapes: effects on functional processes and biodiversity, in: Bradstock, R.A., Williams, J.E., Gill, M.A. (Eds.), Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge University Press, Cambridge, pp. 259-277.
Johnson, C., 2006. Australia's Mammal Extinctions: a 50,000 year history. Cambridge University Press, Port Melbourne.
Jones, P., 1996. Burning Mulga Country to Control Woody Weeds in South-West Queensland. Department of Primary Industries, Charleville.
Krull, E.S., Skjemstad, J.O., Burrows, W.H., Bray, S.G., Wynn, J.G., Bol, R., Spouncer, L., Harms, B., 2005. Recent vegetation changes in central Queensland, Australia: Evidence from 13C and 14C analyses of soil organic matter. Geoderma 126, 241-259.
Latz, P., 2007. The Flaming Desert. Peter Latz, Alice Springs.
Letnic, M., 2000. Dispossession, degradation and extinction: environmental history in arid Australia. Biodiversity and Conservation 9, 295-308.
Ludwig, J.A., Tongway, D.J., 1995. Spatial organisation of landscapes and its function in semi-arid woodlands, Australia. Landscape Ecology 10, 51-63.
Marshall, A.J., 1966. The Great Extermination: a guide to Anglo-Australian cupidity wickedness and waste. William Heinemann Ltd, Melbourne.
Mills, J.R., 1986. Degradation and rehabilitation of the mulga ecosystem, in: Sattler, P.S. (Ed.), The Mulga Lands. Royal Society of Queensland, Brisbane, pp. 79-83.
Mills, J.R., Turner, E.J., Caltobiano, T., 1989. Land degradation in south-western Queensland, Queensland Department of Primary Industries, Brisbane.
Mitchell, P.B., 1991. Historical perspectives on some vegetation and soil changes in semi-arid New South Wales. Vegetatio 91, 169-182.

Moore, C.W.E., 1973. Some observations on ecology and control of woody weeds on mulga lands in north-western New South Wales. Tropical Grasslands 7, 79-88.
Moore, J.L., Howden, S.M., McKeon, G.M., Carter, J.O., Scanlan, J.C., 2001. The dynamics of grazed woodlands in southwest Queensland, Australia and their effect on greenhouse gas emissions. Environment International 27, 147-153.
Newsome, A.E., 1975. An ecological comparison of the two arid-zone kangaroos of Australia, and their anomalous prosperity since the introduction of ruminant stock to their environment. Quarterly Review of Biology 50, 389-424.
Noble, J.C., 1997. The Delicate and Noxious Scrub: CSIRO studies on native tree and shrub proliferation in the semi-arid woodlands of eastern Australia. CSIRO, Canberra.
Noble, J.C., Grice, A.C., 2002. Fire regimes in semi-arid and tropical pastoral lands: managing biological diversity and ecosystem function, in: Bradstock, R.A., Williams, J.E., Gill, M.A. (Eds.) Flammable Australia: the fire regimes and biodiversity of a continent. Cambridge University Press, Cambridge, pp. 373-400.
Oxley, R.E., 1987. Analysis of historical records of a grazing property in south-western Queensland 2. Vegetation changes. Australian Rangeland Journal 9, 30-38.
Pickard, J., 1994. Post-European changes in creeks of semi-arid rangelands, Polpah Station, New South Wales, in: Millington, A.C., Pye, K. (Eds.), Environmental Change in Drylands: biogeographical and geomorphological perspectives. John Wiley & Sons, Chichester, pp. 271-284.
Pople, A.R., Grigg, G., 2001. Commercial Harvesting of Kangaroo in Australia. Environment Australia, Canberra.
Pressland, A.J., 1975. Productivity and management of mulga in south-western Queensland in relation to tree structure and density. Australian Journal of Botany 23, 975-976.
Pressland, A.J., 1984. Productivity and mangement of western Quensland's rangelands. Australian Rangeland Journal 6, 26-45.
Pressland, A.J., Graham, T.W.G., 1989. Approaches to the restoration of rangelands - the Queensland experience. Australian Rangeland Journal 11, 101-109.
Reynolds, J.A., Carter, J.O., 1993. What Landholders Reckon About Woody Weeds in Central Western Queensland. Queensland Deparrtment of Primary Industries, Brisbane.
Reynolds, J.A., Muller, K., Carter, J.O., 1994. Woody weeds 10 years later. 8th Biennial Conference, Australian Rangelands Society, 241-242.
Reynolds, J.A., Muller, K.W., Muller, S.L., 1992. Woody Weeds in Central West Queensland. Department of Primary Industries, Brisbane.
Rolls, E.C., 1984. A Million Wild Acres. Penguin, Ringwood.
Rolls, E.C., 1999. Land of grass: the loss of Australia's grasslands. Australian Geographical Studies 37, 197-213.
Scanlan, J.C., Presland, A.J., 1984. Major Woody Weeds of Western Queensland and Their Control. Information Series Q184017. Queensland Department of Primary Industries, Brisbane.
Silcock, J., 2009. Identification of Permanent Refuge Waterbodies in the Cooper Creek & Georgina-Diamantina catchments. South Australia Arid Lands Natural Resource Management Board, http://www.saalnrm.sa.gov.au/Portals/8/Publications_Resources/Project_Reports (accessed 13 July 2011).
Tolcher, H.M., 1986. Drought or Deluge: man in the Cooper's Creek region. Melbourne University Press, Carlton.
Witt, G.B., Harrington, R.A., Page, M.J., 2009. Is vegetation thickening occurring in Queensland's mulga lands: a 50-year aerial photographic analysis. Australian Journal of Botany 57, 572-582.
Witt, G.B., Luly, J., Fairfax, R.J., 2006. How the west was once: vegetation change in south-west Queensland from 1930-1995. Journal of Biogeography 33, 1585-1596.

Appendix 2-2. Locations mentioned in text (in order of appearance in text)

Explorer	Date	Category	Lat	Long	Quote
Mitchell	22/9/1846	Vegetation	145.00461	-24.12110	the finest region I had ever seen in Australia
Mitchell	15/9/1846	Vegetation	146.25360	-24.68395	most refreshing…on emerging from so many thick scrubs
Kennedy	23/7/1847	Vegetation	146.42398	-24.89410	had to cut thro' a dense Brigalow Scrub'
Walker	1/10/1861	Vegetation	145.97219	-24.53827	dense, almost impenetrable scrub of acacia
Landsborough	1-16/4/1862	Vegetation	144.59333	-22.63222	thinly wooded downs
Landsborough	19/4/1862	Vegetation	143.75444	-24.65028	so thickly wooded...that riding fast was too dangerous to be agreeable
Mitchell	24/9/1846	Vegetation	144.67247	-24.06343	extensive downs, in many parts of which dead brigalow stumps remained
Mitchell	1/10/1846	Vegetation	144.69899	-24.25966	dead trunks alone remained on vast tracts
Kennedy	10-11/8/1847	Vegetation	144.97610	-24.28087	Downs...strewed with dead timber
Kennedy	4/8/1847	Vegetation	145.25255	-24.26960	parched country...completely destitute of vegetation
Kennedy	30/8/1847	Vegetation	143.50767	-25.13077	white clay blistered and cracked and totally devoid of vegetation
Kennedy	2/9/1847	Vegetation	142.73269	-25.48280	not a blade is visible in any direction
Kennedy	7-15/11/1947	Vegetation	145.97119	-27.29529	In no part of the colony have I seen more luxuriant pasture
Kennedy	2/11/1847	Vegetation	146.40210	-26.13912	Acacia scrub...too thick to penetrate
Landsborough	3/5/1862	Vegetation	145.66833	-25.61417	barren scrubby ridges…thickly wooded with mulga
Landsborough	3/5/1862	Vegetation	145.66833	-25.61417	scrub…consisting of mulga with few other trees
Landsborough	6/5/1862	Vegetation	145.59972	-25.91111	well covered with kangaroo grass, but in the last part...it was too scrubby to be well grassed
Landsborough	12/05/1862	Vegetation	146.49833	-26.61472	the country…was so bad that I did not wonder at its not being stocked…
Mitchell	18/5/1846	Fire	147.90696	-26.20573	the natives having availed themselves of a hot wind to burn...the old grass
Mitchell	6/10/1846	Fire	147.02859	-24.97962	we crossed several water-courses, the grass on their banks being green and young, because the old grass had been burnt off by the natives
Mitchell	3/9/1846	Fire	147.32426	-24.52219	Bushes had been burnt all along the line
Landsborough	21/4/1861	Fire	144.02361	-24.57722	On the flats where the old grass had been burned good grass had grown up
Sturt	13/10/1845	Fire	140.46417	-27.74917	luxuriant green burnt feed
Winnecke	6/10/1883	Fire	137.55921	-23.27198	We travelled across bare red sandridges and valleys which have recently been burned
Winnecke	17/9/1883	Fire	137.27487	-23.00639	The country in the immediate vicinity of these hills has been recently burnt
Turner	4/11/1847	Fire	146.16808	-26.50572	bush all on fire'
Kennedy	20/11/1847	Fire	145.96301	-28.67800	...ironbark scrub patches of spinifex; these with a brush of poison were in flames all around...
McKinlay	30/4/1862	Fire	140.80528	-20.28889	Blackfellows burning grass to east-south-east of us; the first bushfire we have seen
Mitchell	13/9/1846	Fire	146.64673	-24.89675	the extensive burning by the natives...
Hodgkinson	12/6/1878	Fire	140.08639	-25.11778	During the night the reflection of a very large fire was visible N.335˚E.

Walker	13/10/1861	Water	144.84661	-23.02808	It will be observed that we have seen very little permanent water…
Kennedy	11/8/1847	Water	144.73744	-24.26563	Shallow creeks
Mitchell	20-25/9/1846	Water	145.45800	-24.42400	Deep permanent waterholes
Kennedy	2/8/-22/9/1847	Water	145.45800	-24.42400	Deep permanent waterholes
Kennedy	6/9/1847	Water	142.66507	-25.66312	…divided into a number of channels but in one of them some small but I think constant holes of water were found'
Greenfell-Thomas	30/10/1919	Water	139.32417	-26.50528	...Andrewilla waterhole – a huge hole 14 miles long…
Landsborough	3/5/1862	Water	145.66833	-25.61417	The channel of the river was of a sandstone formation at some places and had fine holes of water'
Walker	13/10/1861	Water	144.79633	-22.97260	In the first tributary we saw the finest reach of water I have seen this side of the range
Landsborough	25/3/1862	Water	144.60583	-21.59306	The creek has fine deep holes of water
Kennedy	4-15/11/1847	Water	145.97100	-27.29500	Fine, deep reaches
Landsborough	19/5/1862	Water	145.91694	-27.09528	...deep waterhole
Basedow	13/10/1919	Water	140.46944	-26.64361	Reach Bulls W.H. at dusk…practically dry
Kennedy	12/10/1847	Water	146.56452	-25.84874	junction of a creek fro the eastward where water in all seasons may be found
Greenfell-Thomas	1/11/1919	Water	138.96583	-26.88778	a little pool of brine with salt crystals floating on it'
Lewis	9/2/1875	Water	138.96583	-26.88778	a splendid sheet of water...four to five feet deep twenty yards out, and six to seven feet about the centre
Walker	27/10/1861	Water	143.76427	-20.68225	The water...no doubt stands a long time, but...is only 5 feet deep, it cannot be deemed permanent
Lewis	1-10/1/1875	Water	138.26951	-27.70716	Occasional fine waterholes (many salt), interspersed with dry channels
Winnecke	16-20/8/1883	Water	138.28897	-27.47186	Occasional fine waterholes (many salt), interspersed with dry channels
Sturt	4-11/9/1845	Water	138.63417	-24.91833	Mixture of dry, ill-defined channel and wide but shallow expanses of water (some brackish)
Hodgkinson	20/7-15/8/1876	Water	138.61778	-24.96667	Mixture of dry, ill-defined channel and wide but shallow expanses of water (some brackish)
Winnecke	5-6/9/1883	Water	138.63440	-23.90875	Dry channels; fine waterhole glimpsed
Mitchell	11-14/9/1846	Water	146.53734	-24.94515	After tracing it 22 miles, without seeing any water in its bed...found water in single waterhole
Davidson	1885	Water	138.61257	-22.74203	Broad, shallow expanses of water
Mitchell	15-19/9/1846	Water	145.79400	-24.58500	No permanent water
Kennedy	24/7-1/8/1847	Water	145.79400	-24.58500	No permanent water
Kennedy	26/10/1847	Water	147.06306	-25.42181	Reached Kangaroo Creek, which was dry
Sturt	2/9/1845	Water	138.75694	-25.92528	None of the water holes that we find contain more than two or at most three days supply of water…

Landsborough	21-27/12/1861	Water	138.09461	-19.84071	Searched for water unsuccessfully
Sturt	18/8-12/11/1845	Water	140.45833	-28.31778	Broad but shallow waterholes along creek; had dried up by November 1845
Kennedy	18/11/1847	Water	145.74313	-28.27778	parched bed of sand
Landsborough	7/4/1862	Water	143.88361	-23.85194	The holes were deep and mussel shells were abundant on its banks
Landsborough	21-26/12/1861	Water	138.08969	-19.87914	Good waterholes
Lewis	31/1/1875	Water	138.55142	-27.28940	…six feet from the bank it is from eight to ten feet deep, excepting the upper end where we could not get bottom
Winnecke	9/8/1883	Water	140.45833	-28.31778	Camped near Mungeranie Waterhole, which is now quite dry
Sturt	22/8/1845	Water	139.36917	-27.31139	The pool near us is very deep and the water clear…the water I should imagine is permanent
Landsborough	24/3/1862	Water	144.63028	-21.27667	Encamped at a fine waterhole. All along the creek there are fine deep waterholes
Hodgkinson	7/8/1876	Fauna	138.61100	-23.88600	The kangaroo-rats here build nests three feet high against the trunks of giddia or other trees’
Hodgkinson	21/8/1876	Fauna	138.07700	-23.20600	numerous rock wallabies…
Sturt	4/11/1844	Fauna	141.67306	-31.91250	three rock wallabies
Sturt	15/12/1845	Fauna	141.41000	-31.49333	5-6 rock wallabies
Davidson	1885	Fauna	139.91600	-22.90800	one bilby
Mitchell	13/9/1846	Kangaroos	146.63811	-24.91134	plains...heavily imprinted with the feet of kangaroos
Kennedy	2/7/1847	Kangaroos	147.28448	-25.38137	Two Kangaroos were shot today. They are the first we have observed on the journey
Landsborough	30/11/1861	Kangaroos	138.58533	-19.10308	...kangaroos are numerous.
Landsborough	6/1/1862	Kangaroos	138.63576	-19.34412	Kangaroos are numerous on this part of the country…
Landsborough	6/5/1862	Kangaroos	145.90639	-26.03944	In this day's journey we saw more kangaroo and wallaby than on any previous occasion…
Davidson	1885	Kangaroos	139.69500	-22.94300	we noticed a family of three kangaroos, the only ones seen west of Boulia’
McKinlay	15/4/1862	Kangaroos	141.32000	21.93190	Hodgkinson shot a euro which will help us on and save a sheep
McKinlay	17/4/1862	Kangaroos	140.99805	21.66444	Emu and kangaroo in abundance
McKinlay	6/4/1862	Kangaroos	141.86694	-23.13472	Just as I was getting up this hill a fine Euro hopped off…I call the hill Euro Hill
McKinlay	9/4/1862	Kangaroos	141.98333	22.61667	numerous traces of kangaroo…
McKinlay	14/4/1862	Kangaroos	141.32694	22.17528	Lots of kangaroo and emu here but shy
Sturt	16/12/1844	Kangaroos	141.54806	-31.01806	The dogs killed a large Kangaroo this morning
Sturt	19/6/1845	Kangaroos	141.78417	-29.66583	This afternoon one of the Kangaroo dogs caught a Kangaroo in the ranges
Sturt	16/8/1845	Kangaroos	140.67389	-28.53889	Saw several Emus, and numerous tracks of Kangaroos

Appendix 2-3. **Description of broad vegetation types used in explorer analysis**

Broad vegetation type	Brief description
Floodplain woodlands	Open forest and woodland dominated by *Eucalyptus camaldulensis* and/or *Eucalyptus coolabah* fringing drainage lines; does not include alluvial herbfields or grasslands or alluvial plains that are not flooded
Dry eucalypt woodlands	Dry eucalypt woodlands on sandplains or depositional plains, mostly dominated by *Eucalyptus populnea* or *Eucalyptus melanophloia*, in east of study area
Eucalypt-spinifex woodlands	*Eucalyptus* species low open woodland (including *E.leucophloia*, *E.leucophylla*, *E.normantonensis*, *Corymbia terminalis*) with *Triodia* species understorey, mostly on hills and valleys in north of study area
Cypress communities	Woodlands to open forests dominated by *Callitris glaucophylla*
Mulga communities	Woodlands and tall shrublands dominated by *Acacia aneura* on red earth plains or sandplains, becoming pebbly in western areas
Acacia on residuals	Includes low woodlands to tall shrublands dominated by *Acacia* species (mostly *A.stowardii*, *A.shirleyi*, *A. catenulata*) on stony hills, and open shrublands dominated by *Acacia* and *Senna* species on low calcareous hills in the west of the study area
Brigalow communities	Open forest to woodland dominated by *Acacia harpophylla* ± *Casuarina cristata* and *Eucalyptus* species in some areas, on heavy clay soils
Gidgee communities	Open forests to woodlands dominated by *Acacia cambagei* on grey clay, and low open woodlands dominated by *Acacia georginae* in far western Qld and NT
Mixed woodlands	Low open woodlands dominated by a variety of species, including *Lysiphyllum cunninghamii*, *Grevillea striata* and *Atalaya hemiglauca* on sandplains in north of study area
Mitchell grass downs	Tussock grasslands dominated by *Astrebla* species (*Dichanthium* species becoming dominant in eastern areas, *Iseilema* species in some northern areas) on undulating downs or clay plains; includes wooded downs supporting *Acacia tephrina* open woodland
Open forbland	Open forblands, sometimes with scattered grass tussocks, on stony downs and alluvial plains; Chenopodiaceae and Asteraceae species often dominant
Spinifex dunes and sandpains	Hummock grasslands dominated by *Triodia basedowii* (*Triodia marginata* or *mitchellii* in eastern areas) on dunefields or sandplains; sparse mixed shrubs and trees
Sandhills	Extensive low sandhills and undulating plains dominated by annual grass and forb species with mixed shrubs and trees; *Triodia* species occasional or absent (mostly far southern Qld and South Australia)
Wetlands	Swamps and claypans on floodplains dominated by Chenopod species, samphire (*Tecticornia* spp.), *Muehlenbeckia florulenta* and/or herbs, and shallow lakes and claypans in dunefields; includes fringing woodlands and sedgelands

<u>Appendix 2-4.</u> River reaches and waterholes where changes in permanence could be inferred through comparison of explorer record with present-day permanence.

No change was evident for the remaining 23 waterholes or reaches: (i) waterholes judged permanent by explorers still permanent: Barcoo River downstream of Blackall; Cooper Creek from Windorah to Innamincka; Andrewilla Waterhole, Diamantina River; upper Langlo River; Yarraman Waterhole, Rodney Creek; Towerhill Creek, Lammermoor area; Warrego River, Augathella to Cunnamulla, (ii) semi-permanent waterholes remain semi-permanent: Burenda Creek near Augathella; Bulls Waterhole, Cordillo Downs; Goyder Lagoon Waterhole; Flinders River west of Hughenden; Kallakoopah Creek (except Kalamunkinna Waterhole, see table); Mulligan River, Marion Downs to Eyre Creek junction; Long Waterhole, Nive River; Lakes Idamea and Wonditti, Pituri Creek, Glenormiston, (iii) reaches without lasting water still without lasting water: creeks in Mitchell grass downs country; Barcoo River upstream of Blackall; Chesterton Creek; lower Eyre Creek; upper Georgina River, north of Camooweal; Nive River, Malta area; Strzelecki Creek; Warrego River south of Cunnamulla

Reach or area	Explorer/s (observations)	Representative quote or summary	Permanence, 2009*	Inference
Four Mile Creek (Silverfox Creek), tributary of Thomson, south-west of Longreach	Landsborough (1)	'…we crossed a creek which, although now dry, had evident signs of being well watered in good seasons. The holes were deep and mussel shells were abundant…' (7/4/1862)	No deep holes in any of these creeks today – shallow channels in gidgee/downs clay soil	Decreased permanence
Lakes of upper Georgina, near Camooweal	Landsborough & Sutherland† (3)	Had water in for Landsborough, but both went dry during Sutherland's stay (Dec 1860s) – semi-permanent	Lakes Frances and Canellan still semi-permanent; Lake Mary excavated and now permanent	No change/ increased permanence
Kalamunkinna (Junction) Waterhole, Kallakoopah Creek	Lewis (1)	'…six feet from the bank it is from eight to ten feet deep, excepting the upper end where we could not get bottom. Mr Beresford and the black boy vainly tried to ascertain the depth by diving. We then tried in the centre, with a tomahawk tied to a fishing line, without success…' (Lewis, 31/1/1875)	Waterhole has been dry a couple of times in past 20 years, so seems unlikely to be this deep	Decreased permanence
Mungerannie Waterhole	Winnecke (1)	'…camped near Mungeranie Waterhole, which is now quite dry' (9/8/1883)	Permanent due to artesian bore flowing into it	Increased permanence
Talleranie (O'Halloran's) Creek	Sturt (1)	'The pool near us is very deep and the water clear. There are fish in it about 1/2 a pound in weight but we have not taken one. The water I should imagine is permanent.' (22/8/1845)	Only shallow, ephemeral waterholes found in this creek	Decreased permanence
Towerhill Creek, Curragilla to Lammermoor	Landsborough (1)	'…encamped at a fine waterhole. All along the creek there are fine deep waterholes.' (24/3/1862)	No long-lasting waterholes left on Curragilla/Ashton reach	Decreased permanence

* 2009 permanence assessed through interviews with long-term residents

† Sutherland, G., 1913. Across the wilds of Queensland with sheep to the Northern Territory in the early sixties, In *Pioneering Days: Thrilling Incidents*. W.H. Wendt & Coy Ltd Printers, Brisbane.

<u>Appendix 3-1.</u> Frequency and average abundance (in brackets) for all species between treatments and sites. The five species that provide the greatest contribution to the difference between treatments at sites with significant difference (site 1 and site 4) are in bold. Undescribed species are identified with a collector and collecting number relating to specimens at the Queensland Herbarium.

		Site 1		Site 2		Site 3		Site 4		Site 5	
Species	Life form	G	UG	G	UG	G	UG	G	UG	G	UG
Abutilon malvifolium	PH	-	3 (0.8)	-	-	-	-	-	-	-	-
Abutilon otocarpum	PH	1 (0.1)	1 (0.3)	-	1 (0.3)	-	-	-	-	7 (1.8)	9 (2.4)
Alternanthera angustifolia	AH	-	-	5 (1.0)	2 (0.2)	-	-	-	-	-	-
Amaranthus mitchellii	AH	-	-	3 (0.7)	3 (0.4)	-	-	-	-	-	-
Aristida anthoxanthoides	AG	-	-	-	2 (0.4)	-	-	-	-	-	-
Aristida contorta	AG	10 (2.3)	8 (1.6)	-	-	-	2 (0.3)	**8 (2.7)**	**7 (2.8)**	9 (3.3)	9 (3.3)
Astrebla pectinata	PG	-	-	-	-	-	2 (0.5)	-	-	-	-
Atriplex angulata	AH	-	-	1 (0.1)	2 (0.4)	-	-	-	-	-	-
Atriplex holocarpa	AH	-	1 (0.2)	-	1 (0.1)	6 (1.9)	7 (2.1)	3 (1.1)	2 (0.6)	-	-
Atriplex limbata	PH	-	-	-	-	-	-	-	1 (0.1)	-	-
Boerhaevia pubescens	PH	7 (1.6)	1 (0.4)	-	-	-	-	-	-	3 (0.8)	1 (0.2)
Boerhaevia schomburgkiana	PH	-	2 (0.7)	3 (0.7)	7 (2.1)	-	1 (0.4)	-	-	-	-
Brachyachne convergens	AG	-	-	-	-	7 (2.0)	9 (2.8)	-	-	-	-
Bulbine semibarbata	AH	-	-	9 (3.3)	7 (2.3)	-	-	-	-	-	-
Calotis hispidula	AH	-	-	8 (2.2)	2 (0.4)	-	-	-	-	-	-
Calotis lappulacea	AH	-	-	9 (2.7)	5 (1.0)	-	-	-	-	-	-
Calotis plumulifera	AH	-	1 (0.3)	4 (0.7)	3 (0.6)	-	-	1 (0.2)	2 (0.3)	-	-
Chaemacsyce sp. M. Thomas 3620	AH	4 (0.4)	-	-	-	-	1 (0.1)	1 (0.3)	-	-	-
Chenopodium auricomum	PH	-	-	1 (0.3)	1 (0.1)	-	-	-	-	-	-
Chloris pectinata	AG	-	-	5 (1.0)	4 (0.6)	-	-	-	-	-	1 (0.1)
Convolvulus clementii	AH	3 (0.5)	5 (1.4)	1 (0.2)	3 (0.6)	-	-	-	-	-	2 (0.5)
Cullen cinereum	PH	-	3 (0.5)	2 (0.7)	4 (1.1)	-	-	-	-	-	-
Cullen pallidum	PH	-	-	-	-	-	-	-	-	2 (0.4)	4 (0.7)
Cyperus bifax	PH	-	-	-	1 (0.2)	-	-	-	-	-	-
Cyperus iria	AH	-	-	-	1 (0.1)	-	-	-	-	-	-

Species	Life form	Site 1		Site 2		Site 3		Site 4		Site 5	
		G	UG	G	UG	G	UG	G	UG	G	UG
Dactyloctenium radulans	AG	10 (3.4)	10 (4.0)	7 (1.4)	3 (1.0)	9 (3.3)	9 (3.4)	**7 (2.6)**	**9 (2.2)**	7 (2.2)	8 (2.1)
Dichanthium sericeum	AG	1 (0.1)	3 (0.5)	1 (0.1)	3 (0.7)	6 (1.5)	6 (1.5)	4 (0.7)	1 (0.1)	-	-
Einadia nutans	PH	-	-	2 (0.4)	-	-	-	-	-	-	-
Enchylaena tomentose	PH	-	-	1 (0.1)	-	-	-	-	-	-	-
Enneapogon avenaceus	AG	9 (3.1)	10 (4.0)	-	3 (0.7)	9 (2.6)	8 (2.6)	10 (3.7)	10 (3.7)	10 (3.8)	10 (3.5)
Enneapogon polyphyllus	AG	9 (3.1)	10 (3.7)	1 (0.1)	3 (0.6)	10 (4.0)	10 (3.9)	9 (3.3)	10 (3.5)	10 (3.8)	9 (3.1)
Eragrostis basedowii	AG	-	-	1 (0.2)	-	-	-	-	-	-	-
Eragrostis dielsii	AG	10 (2.8)	7 (1.5)	4 (1.2)	4 (1.2)	-	-	**7 (1.5)**	**2 (0.5)**	-	4 (1.1)
Eragrostis leptocarpa	AG	-	-	4 (0.6)	4 (0.8)	-	-	-	-	-	-
Eragrostis setifolia	PG	-	-	3 (0.9)	2 (0.7)	-	-	-	-	-	-
Eragrostis tenellula	AG	-	-	3 (0.5)	2 (0.2)	-	-	-	-	-	-
Eriachne aristidea	AG	-	-	-	-	-	-	3 (0.5)	2 (0.4)	-	-
Erodium carolinianum	AH	-	3 (0.6)	-	-	-	-	-	-	-	-
Eucalyptus coolabah	T	-	-	7 (1.3)	3 (0.8)	-	-	-	-	-	-
Euphorbia tannensis subsp. *Eremophila*	AH	-	2 (0.3)	-	2 (0.2)	-	-	1 (0.1)	1 (0.3)	5 (1.0)	6 (1.2)
Evolvulus alsinoides var. *villosicalyx*	AH	-	-	-	-	-	-	-	-	3 (0.7)	-
Fimbristylis dichotoma	PH	**8 (1.8)**	**9 (2.8)**	-	-	4 (0.6)	2 (0.4)	10 (3.9)	10 (4.0)	8 (2.8)	8 (2.8)
Frankenia gracilis	PH	-	-	-	-	-	-	-	1 (0.1)	-	-
Gilesia biniflora	PH	-	6 (1.6)	-	-	-	-	-	-	1 (0.2)	-
Gnephosis eriocarpa	AH	-	-	1 (0.1)	5 (1.1)	-	-	-	1 (0.1)	-	-
Goodenia fascicularis	AH	3 (0.3)	2 (0.5)	-	-	1 (0.2)	1 (0.3)	-	-	-	2 (0.3)
Goodenia sp. RJ Fensham 5979	AH	-	-	2 (0.6)	3 (0.5)	-	-	-	-	-	-
Hakea leucoptera	S	-	-	-	-	-	-	-	-	-	1 (0.1)
Heliotropium cunninghamii	AH	-	-	-	-	-	-	2 (0.3)	-	-	-
Heliotropium moorei	AH	1 (0.3)	-	-	-	-	-	-	-	-	-
Hibiscus brachysiphonius	PH	1 (0.2)	3 (0.9)	-	-	-	1 (0.3)	-	-	-	-
Hibiscus krichauffianus	PH	5 (1.2)	1 (0.2)	-	-	-	-	-	-	-	-
Indigastrum parviflorum	AH	2 (0.3)	9 (1.9)	-	-	-	-	-	-	-	-
Indigofera colutea	AH	10 (1.6)	6 (1.4)	-	-	-	-	5 (1.4)	-	6 (1.4)	7 (1.4)
Indigofera hirsute	AH	-	-	1 (0.2)	-	-	-	-	-	-	-

Species	Life form	Site 1		Site 2		Site 3		Site 4		Site 5	
		G	UG	G	UG	G	UG	G	UG	G	UG
Indigofera linnaei	AH	10 (1.4)	7 (1.8)	-	-	-	1 (0.1)	-	-	5 (0.7)	4 (0.6)
Ipomoea polymorpha	AH	**8 (2.7)**	**5 (1.2)**	-	1 (0.3)	-	-	1 (0.1)	-	7 (1.3)	7 (2.2)
Iseilema membranaceum	AG	-	-	-	1 (0.2)	-	-	-	-	-	-
Iseilema vaginiflorum	AG	-	3 (0.5)	-	-	-	4 (0.9)	-	-	-	-
Lepidium phlebopetalum	AH	4 (0.7)	5 (1.1)	-	-	6 (0.9)	-	**7 (2.2)**	**10 (3.4)**	7 (2.0)	9 (1.9)
Leptochloa fusca	AG	-	-	-	-	-	-	-	-	-	-
Lotus cruentus	AH	-	-	-	-	-	-	-	-	1 (0.1)	-
Maireana coronata	PH	-	-	1 (0.3)	1 (0.1)	6 (1.3)	5 (1.4)	-	1 (0.1)	-	2 (0.3)
Maireana macrocarpa	PH	-	-	-	-	-	-	1 (0.2)	-	-	-
Muehlenbeckia florulenta	PH	-	-	1 (0.1)	-	-	-	-	-	-	-
Nicotiana velutina	AH	-	-	7 (1.1)	1 (0.1)	-	-	-	-	-	-
Phyllanthus lacunarius	AH	-	-	3 (1.0)	5 (1.3)	-	-	-	-	-	-
Portulaca filifolia	AH	-	-	-	-	2 (0.4)	1 (0.4)	-	-	-	-
Portulaca oleracea	AH	**-**	**6 (2.0)**	10 (3.6)	10 (3.7)	9 (2.9)	5 (1.2)	**2 (0.8)**	**-**	1 (0.3)	1 (0.2)
Pterocaulon spathulatum	AH	-	-	-	1 (0.3)	-	-	-	-	-	-
Ptilotus obovatus	PH	-	-	-	-	-	-	1 (0.3)	-	-	-
Ptilotus polystachyus	AH	-	-	-	-	-	-	2 (0.2)	-	2 (0.6)	-
Rhodanthe moschatum	AH	-	-	2 (0.2)	-	-	-	-	-	-	-
Salsola kali	AH	5 (0.6)	7 (1.6)	3 (0.4)	2 (0.5)	10 (3.2)	10 (3.0)	9 (2.8)	10 (3.0)	5 (0.9)	2 (0.4)
Sauropus trachyspermus	AH	1 (0.1)	-	-	-	-	-	-	-	-	-
Sclerolaena bicornis	PH	-	-	4 (0.9)	1 (0.1)	-	-	3 (0.6)	8 (1.4)	8 (2.0)	5 (1.2)
Sclerolaena calcarata	PH	-	-	3 (0.7)	3 (0.8)	-	-	-	-	-	-
Sclerolaena cuneata	PH	-	-	-	-	-	-	-	4 (1.2)	-	-
Sclerolaena decurrens	PH	-	-	-	-	-	-	1 (0.1)	-	-	-
Sclerolaena diacantha	PH	3 (0.6)	2 (0.6)	1 (0.1)	1 (0.2)	-	-	-	-	-	-
Sclerolaena glabra	PH	-	-	-	-	9 (2.5)	9 (2.2)	2 (0.8)	1 (0.2)	-	1 (0.1)
Sclerolaena intricate	PH	-	-	2 (0.4)	3 (0.8)	-	-	-	-	-	-
Sclerolaena lanicuspis	PH	3 (0.8)	4 (0.8)	-	-	10 (4.0)	10 (4.0)	7 (1.6)	9 (2.1)	1 (0.2)	-
Sclerolaena parallelicuspis	PH	-	-	-	-	7 (1.4)	8 (2.2)	-	1 (0.4)	-	-
Senecio depressicola	AH	-	-	-	1 (0.1)	-	-	-	-	-	-

Species	Life form	Site 1 G	Site 1 UG	Site 2 G	Site 2 UG	Site 3 G	Site 3 UG	Site 4 G	Site 4 UG	Site 5 G	Site 5 UG
Sida ammophila	PH	3 (0.6)	1 (0.2)	-	-	-	-	2 (0.4)	-	-	-
Sida cunninghamii	PH	2 (0.4)	-	-	-	-	-	-	-	1 (0.1)	-
Sida fibulifera	PH	**8 (1.7)**	**11 (3.5)**	-	1 (0.1)	2 (0.6)	4 (0.7)	2 (0.6)	-	1 (0.1)	-
Sida goniocarpa	PH	1 (0.1)	6 (1.1)	-	-	-	-	-	-	-	-
Sida trichopoda	PH	-	-	-	1 (0.2)	1 (0.4)	-	-	-	-	-
Solanum esuriale	PH	-	-	2 (0.4)	-	-	-	-	-	-	-
Sporobolus actinocladus	AG	-	4 (1.0)	1 (0.1)	2 (0.2)	9 (2.9)	10 (3.7)	2 (0.4)	-	-	-
Streptoglossa adscendens	AH	-	-	-	1 (0.2)	-	-	-	-	-	-
Swainsona burkei	AH	9 (2.4)	9 (2.8)	-	-	-	-	2 (0.7)	3 (1.0)	7 (1.4)	4 (1.2)
Swainsona oroboides	AH	-	1 (0.2)	-	-	-	-	-	-	-	-
Tephrosia sphaerospora	PH	8 (1.6)	2 (0.4)	-	-	-	-	-	-	-	1 (0.1)
Tetragonia moorei	AH	-	-	4 (1.2)	3 (0.6)	-	-	-	-	-	-
Teucrium racemosum	PH	-	-	4 (1.2)	2 (0.2)	-	-	-	-	-	-
Tragus australiense	AG	9 (2.4)	10 (3.3)	2 (0.6)	3 (0.8)	9 (3.3)	10 (3.5)	-	-	5 (0.7)	4 (0.8)
Tribulus eichlerianus	AH	**10 (4.0)**	**8 (1.9)**	2 (0.3)	3 (1.0)	-	-	1 (0.2)	-	10 (3.6)	8 (2.6)
Trigonella suavassisima	AH	-	-	8 (2.1)	6 (1.8)	-	-	-	-	-	-
Tripogon lolliiformis	AG	10 (3.5)	10 (3.2)	-	-	8 (2.4)	8 (1.7)	10 (3.8)	10 (3.7)	10 (3.8)	8 (2.9)
Triraphis mollis	AG	1 (0.1)	1 (0.3)	2 (0.4)	5 (1.6)	-	-	3 (0.6)	-	-	3 (0.7)
Urochloa subquadripara	AG	5 (0.8)	2 (0.5)	-	-	-	-	-	-	4 (1.2)	3 (0.3)
Zaleya galericulata	PH	-	-	-	4 (1.0)	-	-	-	-	-	-
Zygophyllum apiculatum	AH	-	-	1 (0.3)	-	-	2 (0.8)	-	-	-	-

<u>Appendix 4-1.</u> Listed (Endangered, Vulnerable and Near Threatened) and candidate (Least Concern) species, western Queensland

Family	Species	Conservation Status, Qld NCA (EPBC Act)	Form of Rarity	Distribution[A]	Number of Records, QLD (All Regions)	Last Collected, QLD	Life Form[B]	Habitat
Acanthaceae	*Rhaphidospora bonneyana*	V (V)	R7	ML; MGD	11 (13)	2009	PF	Residuals
Acanthaceae	*Xerothamnella parvifolia*	V (V)	R5	ML; CHC	16 (18)	2009	PF	Residuals
Aizoaceae	*Gunniopsis papillata*	LC	R1	CHC; ML; MGD; NWH (SA, NSW)	5 (11)	1989	PF	Residuals
Aizoaceae	*Gunniopsis sp.* (Edgbaston R.J.Fensham 5094)	LC	R7	MGD	1 (1)	2010	AF	Spring wetland
Amaranthaceae	*Nyssanthes* (Budgerygar)	LC	R7	ML	1 (1)	1997	PF	Residuals
Amaranthaceae	*Nyssanthes* (Mt Booka Booka)	LC	R5	MGD	2 (2)	2009	PF	Residuals
Amaranthaceae	*Ptilotus brachyanthus*	E	R6	MGD; ML (NT)	7 (8)	2009	PF	Variable
Amaranthaceae	*Ptilotus maconochiei*	NT	R5	MGD; CHC; NWH	18 (18)	2005	PF	Residuals
Amaranthaceae	*Ptilotus pseudohelipteroides*	NT	R1	CHC; ML; MGD	13 (22)	2009	AF	Residuals
Amaranthaceae	*Ptilotus remotiflorus*	LC	R5	MGD; CHC; ML (NSW)	16 (18)	2009	PF	Residuals
Apiaceae	*Actinotus paddisonii*	NT	R5	ML; BB (NSW)	5 (12)	1998	PF	Sandy red earth
Apiaceae	*Eryngium fontanum*	E (E)	R5	MGD	7 (7)	2005	AqF	Spring wetland
Apocynaceae	*Cerbera dumicola*	NT	R5	MGD; BB; EU	37 (37)	2005	S	Residuals
Araceae	*Typhonium alismifolium*	LC	R5	MGD (NT)	1 (2)	1988	L	Acacia woodland
Araliaceae	*Hydrocotyle dipleura*	V	R5	MGD; ML	6 (6)	2005	PF	Spring wetland
Araliaceae	*Trachymene clivicola*	LC	R5	MGD; CHC	9 (9)	2005	AF	Residuals
Asteraceae	*Brachyscome tesquorum*	NT	R3	CHC (NT)	2 (44)	2007	PF	Other wetland
Asteraceae	*Calocephalus* (Lake Huffer)	LC	R5	MGD; DU	5 (5)	2006	AF	Spring wetland
Asteraceae	*Calocephalus sp.* (Eulo M.E.Ballingall MEB2590)	NT	R5	ML	7 (7)	2004	AF	Spring wetland
Asteraceae	*Calotis suffruticosa*	NT	R5	MGD; CHC	3 (3)	1981	PF	Downs
Asteraceae	*Ixiochlamys integerrima*	LC	R2	CHC; MGD; NWH (NT, SA)	6 (25)	1981	AF	Limestone
Asteraceae	*Picris barbarorum*	V	R5	MGD; ML; BB (NSW)	16 (20)	2008	AF	Downs
Asteraceae	*Rhodanthe rufescens*	NT	R5	ML; CHC	4 (4)	2006	AF	Residuals
Asteraceae	*Vittadinia decora*	NT	R5	ML	4 (4)	2009	PF	Sandy red earth
Boraginaceae	*Heliotropium chalcedonium*	LC	R7	MGD	1 (1)	1947	PF	Limestone

Family	Species	Conservation Status, Qld NCA (EPBC Act)	Form of Rarity	Distribution[A]	Number of Records, QLD (All Regions)	Last Collected, QLD	Life Form[B]	Habitat
Brassicaceae	*Arabidella sp.* (Eurella S.L.Everist 3734)	LC	R4	ML; MGD; BB (NSW)	3 (4)	1949	PF	Acacia woodland
Campanulaceae	*Isotoma sp.* (Myross R.J.Fensham 3883)	LC	R7	MGD	2 (2)	2007	PF	Spring wetland
Campanulaceae	*Isotoma sp.* (Elizabeth Springs)	LC	R1	MGD	1 (1)	1999	AqF	Spring wetland
Chenopodiaceae	*Atriplex fissivalvis*	LC	R5	CHC (NT, SA, NSW)	4 (10)	2010	AF	Residuals
Chenopodiaceae	*Atriplex lobativalvis*	NT	R5	CHC (NT, SA, NSW)	2 (50)	1988	AF	Ephemeral wetland
Chenopodiaceae	*Atriplex morrisii*	V	R6	ML (SA, NSW)	1 (9)	1936	AF	Residuals
Chenopodiaceae	*Chenopodium hubbardii*	LC	R5	ML; MGD; BB; DU	14 (14)	1967	AF	Acacia woodland
Chenopodiaceae	*Dysphania valida*	LC	R4	ML; BB	6 (6)	1970	PF	Variable
Chenopodiaceae	*Maireana cheelii*	LC (V)	R3	ML; CHC (NSW, VIC)	3 (20)	2008	PF	Ephemeral wetland
Chenopodiaceae	*Maireana lanosa*	LC	R3	CHC; MGD (NT)	5 (20)	1990	PF	Variable
Chenopodiaceae	*Osteocarpum pentapterum*	LC	R3	CHC (SA)	4 (12)	1995	PF	Residuals
Chenopodiaceae	*Osteocarpum scleropterum*	LC	R7	ML (NSW)	2 (5)	1955	PF	Ephemeral wetland
Chenopodiaceae	*Sclerolaena blackiana*	NT	R6	CHC (SA, NSW)	3 (30)	2005	PF	Downs
Chenopodiaceae	*Sclerolaena blakei*	V (V)	R7	CHC	1 (1)	1936	PF	Residuals
Chenopodiaceae	*Sclerolaena walkeri*	V (V)	R1	ML; CHC; MGD (NSW)	13 (14)	2009	PF	Ephemeral wetland
Convolvulaceae	*Duperreya halfordii*	LC	R7	ML; BB (NSW)	2 (4)	1972	V	Residuals
Cucurbitaceae	*Austrobryonia argillicola*	E (E)	R3	MGD (NT)	15 (20)	2009	PF	Downs
Cyperaceae	*Eleocharis blakeana*	NT	R1	ML; BB	26 (28)	2007	Sedge	Other wetland
Cyperaceae	*Fimbristylis sp.* (Elizabeth Springs R.J.Fensham 3743)	LC	R1	MGD (SA)	5 (7)	2004	Sedge	Spring wetland
Cyperaceae	*Schoenus centralis*	LC	R3	ML; BB (NSW, NT, WA)	2 (7)	1984	Sedge	Other wetland
Eriocaulaceae	*Eriocaulon aloefolium*	E (CE)	R5	MGD	2 (2)	2006	AqF	Spring wetland
Eriocaulaceae	*Eriocaulon carsonii*	E (E)	R1	MGD; ML; DU; EU; GP; BB (SA, NSW)	20 (23)	2004	AqF	Spring wetland
Eriocaulaceae	*Eriocaulon giganticum*	E (CE)	R5	MGD	1 (1)	1998	AqF	Spring wetland
Euphorbiaceae	*Euphorbia sarcostemmoides*	V	R1	ML; CHC; DU (NT)	21 (97)	2006	S	Residuals
Euphorbiaceae	*Ricinocarpos crispatus*	LC	R5	ML	11 (11)	2000	S	Residuals
Fabaceae	*Indigofera haematica*	LC	R5	CHC; MGD; DU	8 (8)	2009	PF	Residuals
Fabaceae	*Indigofera oxyrachis*	V	R7	CHC; ML	3 (3)	1989	PF	Residuals

Family	Species	Conservation Status, Qld NCA (EPBC Act)	Form of Rarity	Distribution[A]	Number of Records, QLD (All Regions)	Last Collected, QLD	Life Form[B]	Habitat
Fabaceae	*Swainsona similis*	LC	R2	ML (NSW)	3 (8)	1976	PF	Sandy red earth
Fabaceae	*Vigna sp.* (McDonald Downs Station R.A.Perry 3416)	LC	R4	CHC; GP; NWH (NT)	5 (6)	2008	V	Variable
Goodeniaceae	*Goodenia angustifolia*	NT	R5	CHC; MGD; NWH (NT)	6 (32)	2005	PF	Variable
Goodeniaceae	*Goodenia atriplexifolia*	LC	R7	ML; CHC	9 (9)	2008	PF	Residuals
Goodeniaceae	*Goodenia expansa*	LC	R5	ML; CHC	6 (6)	2005	AF	Sandy red earth
Haloragaceae	*Myriophyllum artesium*	E	R1	ML; MGD; DU; BB	14 (14)	2004	AqF	Spring wetland
Johnsoniaceae	*Caesia chlorantha*	LC	R3	ML; BB (NT)	12 (18)	1998	L	Downs
Johnsoniaceae	*Corynotheca licrota*	LC	R1	ML (NSW, NT, SA, VIC)	3 (40)	1984	L	Sandy red earth
Malvaceae	*Sida argentea*	LC	R6	ML; BB (NSW)	4 (6)	2003	PF	Other wetland
Malvaceae	*Sida asterocalyx*	LC	R7	ML; CHC	10 (10)	2001	PF	Residuals
Mimosaceae	*Acacia* (Cowley)	LC	R5	ML	5 (5)	2009	T	Acacia woodland
Mimosaceae	*Acacia ammophila*	V (V)	R4	ML	31 (31)	1999	T	Sandy red earth
Mimosaceae	*Acacia crombiei*	V (V)	R5	MGD; EU; DU; GP	32 (32)	2005	T	Variable
Mimosaceae	*Acacia peuce*	V	R5	CHC; MGD (NT)	31 (35)	2005	T	Variable
Mimosaceae	*Acacia philoxera*	LC	R7	ML	3 (3)	2000	S	Residuals
Mimosaceae	*Acacia sp.* (Ambathala C.Sandercoe 624)	LC	R5	ML	3 (3)	2006	T	Residuals
Mimosaceae	*Acacia sp.* (Fermoy Road I.V.Newman 487)	LC	R5	CHC; MGD; ML	8 (8)	2010	T	Residuals
Mimosaceae	*Acacia spania*	NT	R4	ML; DU; BB	14 (14)	2006	T	Variable
Molluginaceae	*Glinus orygioides*	LC	R2	CHC (NT, WA)	3 (20)	1988	PF	Other wetland
Myoporaceae	*Eremophila arbuscula*	LC	R5	ML	15 (15)	2000	T	Residuals
Myoporaceae	*Eremophila stenophylla*	LC	R5	ML; CHC	20 (20)	2010	S	Acacia woodland
Myoporaceae	*Eremophila tetraptera*	V (V)	R5	MGD; CHC	10 (10)	2005	S	Variable
Myrtaceae	*Kunzea*	LC	R5	ML	1 (1)	2010	S	Residuals
Myrtaceae	*Melaleuca kunzeoides*	V (V)	R5	ML	7 (7)	2009	S	Residuals
Myrtaceae	*Melaleuca sp.* (Mt Marlow M.E. Ballingall MEB2737)	LC	R5	MGD	3 (3)	1999	S	Acacia woodland
Myrtaceae	*Micromyrtus rotundifolia*	V	R5	ML; DU; BB	8 (8)	2004	S	Residuals
Myrtaceae	*Thryptomene hexandra*	NT	R1	ML	33 (39)	2009	S	Residuals
Nymphaeaceae	*Nymphaea georginae*	LC	R1	MGD (NT)	2 (5)	2006	AqF	Other wetland
Phyllanthaceae	*Phyllanthus involutus*	LC	R7	ML (NSW)	2 (4)	2004	PF	Residuals

Family	Species	Conservation Status, Qld NCA (EPBC Act)	Form of Rarity	Distribution[A]	Number of Records, QLD (All Regions)	Last Collected, QLD	Life Form[B]	Habitat
Phyllanthaceae	*Sauropus ramosissimus*	LC	C	ML; CHC; DU; BB; GP (NT, WA, NSW, SA)	9 (20)	2006	PF	Residuals
Poaceae	*Austrochloris dichanthioides*	LC	R6	ML; MGD; CHC; DU; NWH	20 (20)	2008	PG	Variable
Poaceae	*Austrostipa blakei*	LC	R6	ML; BB (NSW)	9 (11)	2002	PG	Sandy red earth
Poaceae	*Chloris* sp. (Edgbaston R.J.Fensham 5694)	LC	R7	MGD	1 (1)	2009	AG	Spring wetland
Poaceae	*Dactyloctenium buchananensis*	LC	R5	MGD; DU; EU; BB	12 (12)	2008	AG	Other wetland
Poaceae	*Digitaria hubbardii*	LC	R5	ML; BB (NSW)	14 (19)	2008	PG	Sandy red earth
Poaceae	*Eragrostis fenshamii*	LC	R5	ML; MGD	3 (3)	2009	PG	Spring wetland
Poaceae	*Iseilema calvum*	LC	R7	MGD; GP (NT)	17 (19)	1991	AG	Downs
Poaceae	*Neurachne munroi*	LC	R2	ML; CHC; MGD; DU; NWH (NT, SA, NSW, WA)	37 (120)	2006	PG	Variable
Poaceae	*Schizachyrium perplexum*	LC	R3	MGD; NWH; GP; EU (NT)	12 (15)	2006	AG	Residuals
Poaceae	*Spathia neurosa*	LC	R5	MGD; CHC (NT)	8 (20)	2002	AG	Downs
Poaceae	*Sporobolus pamelae*	E	R5	ML; MGD; DU	7 (7)	1999	PG	Spring wetland
Poaceae	*Sporobolus partimpatens*	NT	R1	ML; CHC; BB; DU	14 (14)	2008	PG	Spring wetland
Poaceae	*Urochloa atrisola*	LC	R2	MGD; GP (NT)	6 (8)	2002	AG	Downs
Poaceae	*Yakirra websteri*	LC	R7	ML; BB	2 (2)	1975	PG	Sandy red earth
Portulacaceae	*Calandrinia* sp. (Lumeah R.W.Purdie 2168)	LC	R7	ML; CHC; DU	4 (4)	2009	AF	Residuals
Proteaceae	*Grevillea kennedyana*	V (V)	R5	CHC (NSW)	3 (7)	1998	S	Residuals
Proteaceae	*Hakea maconochieana*	NT	R5	ML	15 (15)	2000	S	Residuals
Rubiaceae	*Oldenlandia spathulata*	E	R5	MGD; GP (NT)	3 (4)	2009	AF	Downs
Sapindaceae	*Dodonaea intricata*	LC	R5	ML (SA?)	6 (8)	2001	S	Residuals
Scrophulariaceae	*Elacholoma hornii*	NT	R1	ML; CHC (NT, WA, SA, NSW)	2 (30)	1973	AF	Variable
Scrophulariaceae	*Peplidium* sp. (Edgbaston R.J.Fensham 3341)	LC	R5	MGD	2 (2)	1998	AF	Spring wetland
Solanaceae	*Solanum versicolor*	LC	R7	ML	4 (4)	2007	PF	Sandy red earth

Family	Species	Conservation Status, Qld NCA (EPBC Act)	Form of Rarity	Distribution[A]	Number of Records, QLD (All Regions)	Last Collected, QLD	Life Form[B]	Habitat
Surinaceae	*Cadellia pentastylis*	V (V)	R5	ML; BB; MGD (NSW)	59 (65)	2005	T	Residuals
Zygophyllaceae	*Roepera humillima*	LC	R7	CHC (SA)	2 (2)	2005	AF	Downs
Zygophyllaceae	*Roepera rowelliae*	LC	R7	CHC (NT)	1 (15)	1971	AF	Limestone

[A] Bioregions: ML = Mulga Lands, CHC = Channel Country, MGD = Mitchell Grass Downs, NWH = North West Highlands, DU = Desert Uplands, GP = Gulf Plains, BB = Brigalow Belt, EU = Einasleigh Uplands (States: NT = Northern Territory, NSW = New South Wales, SA = South Australia, WA = Western Australia, Vic = Victoria)

[B] Life forms, see Table 4-8

<u>Appendix 5-1.</u> Plant species recorded in northern Grey Range, Queensland, Australia and percentage occurrence in the 88 detailed sites recorded by habitat.

Family	Species	Life form	Barren plateau	Bendee slope	Bendee tabeland	Gidgee toeslope	Mulga tabeland	Shrubby tabeland
Acanthaceae	*Brunoniella australis*	PH		19	13		27	
Acanthaceae	*Dipteracanthus australasica*	PH				15		
Acanthaceae	*Rhaphidospora bonneyana*	S				8		
Acanthaceae	*Xerothamnella parvifolia*	S				62		
Adiantaceae	*Cheilanthes distans*	PF		6				
Adiantaceae	*Cheilanthes sieberi*	PF					80	55
Aizoaceae	*Trianthema triquetra*	AH				54		
Amaranthaceae	*Achyranthes aspera*	AH		6		8		
Amaranthaceae	*Alternanthera denticulata*	AH		19	13	15	13	9
Amaranthaceae	*Ptilotus decipiens*	AH		6				9
Amaranthaceae	*Ptilotus nobilis*	PH				8		
Amaranthaceae	*Ptilotus obovatus*	PH		13		15		
Amaranthaceae	*Ptilotus pedleyanus*	S		31				
Amaranthaceae	*Ptilotus royceanus*	PH		6				
Apiaceae	*Trachymene cyanantha*	AH					20	36
Apocynaceae	*Parsonsia eucalyptophylla*	PV		6				
Apocynaceae	*Sarcostemma australe*	PV		6		8		
Asphodelaceae	*Bulbine alata*	AL				8		
Asteraceae	*Calotis cuneifolia*	PH		13	7		40	18
Asteraceae	*Calotis hispidula*	AH						18
Asteraceae	*Calotis lappulacea*	PH						9
Asteraceae	*Calotis latiuscula*	PH					13	9
Asteraceae	*Epaltes australis*	AH						18
Asteraceae	*Pluchea rubelliflora*	PH			7			9
Asteraceae	*Podolepis canescens*	AH					7	
Asteraceae	*Pterocaulon serrulatum*	AH		19	7	23	53	18
Asteraceae	*Pterocaulon sphacelatum*	AH		6		15	40	27
Asteraceae	*Verbesina encelioides**	AH			13	15		
Asteraceae	*Vittadinia sulcate*	PH		6		15	33	
Bignoniaceae	*Pandorea pandorana*	PV		6	20		13	
Boraginaceae	*Ehretia membranifolia*	S				8		
Boraginaceae	*Helitropium cunninghamii*	PH						9
Brassicaceae	*Stenopetalum decipiens*	PH		6				
Caesalpiniaceae	*Lysiphyllum caronii*	T		6				
Caesalpiniaceae	*Petalostylis labicheoides*	S					7	
Caesalpiniaceae	*Senna artemisioides* subsp. *filifolia*	S		6		23	7	
Caesalpiniaceae	*Senna artemesioides* subsp*. zygophylla*	S				8	7	
Caesalpiniaceae	*Senna artemisioides* subsp. *artemisioides*	S					7	
Caesalpiniaceae	*Senna artemisioides* subsp. *helmsii*	S	6	6			13	55
Caesalpiniaceae	*Senna artemisioides* subsp. *oligophylla*	S				38	7	9
Caesalpiniaceae	*Senna phyllodinea*	S				8		
Caesalpiniaceae	*Senna pleurocarpa*	S					7	
Campanulaceae	*Wahlenbergia gracilis*	AH					27	
Capparaceae	*Capparis lasiantha*	S		38	7	15		
Carophyllaceae	*Polycarpaea multicaulis*	PH	6					

Family	Species	Life form	Barren plateau	Bendee slope	Bendee tabeland	Gidgee toeslope	Mulga tabeland	Shrubby tabeland
Chenopodiaceae	*Atriplex humifusa*	PH				8		
Chenopodiaceae	*Atriplex limbata*	PH				8		
Chenopodiaceae	*Atriplex lindleyi*	AH				8		
Chenopodiaceae	*Chenopodium desertorum*	PH		6	13	85		
Chenopodiaceae	*Dissocarpos paradoxus*	PH				23		
Chenopodiaceae	*Dysphania glomulifera*	AH	11	44	33	8	33	64
Chenopodiaceae	*Dysphania rhadinostachya*	AH	6				13	
Chenopodiaceae	*Einadia nutans*	PH		38	7			
Chenopodiaceae	*Enchylaena tomentosa*	PH		25	7	92		
Chenopodiaceae	*Maireana campanulata*	PH				23		
Chenopodiaceae	*Maireana georgeii*	PH		6		23		
Chenopodiaceae	*Maireana triptera*	PH	6			69		9
Chenopodiaceae	*Maireana villosa*	PH	28	38	47	54	7	
Chenopodiaceae	*Neobassia proceriflora*	PH				15		
Chenopodiaceae	*Rhagodia spinescens*	S				15		
Chenopodiaceae	*Salsola kali*	AH	6			38		
Chenopodiaceae	*Sclerolaena birchii*	PH				8		
Chenopodiaceae	*Sclerolaena calcarata*	PH				31		
Chenopodiaceae	*Sclerolaena convexula*	PH		31				
Chenopodiaceae	*Sclerolaena cuneata*	PH	6	13				
Chenopodiaceae	*Sclerolaena diacantha*	PH		31		77		
Chenopodiaceae	*Sclerolaena glabra*	PH				15		
Chenopodiaceae	*Sclerolaena lanicuspis*	PH				77		
Chenopodiaceae	*Sclerolanea longicuspis*	PH				15		
Convolvulaceae	*Convolvulus clementii*	PV					7	
Convolvulaceae	*Evolvulus alsinoides*	PH					40	45
Convolvulaceae	*Ipomoea calobra*	PV		6	7		40	9
Convolvulaceae	*Ipomoea polpha*	PV					7	9
Cyperaceae	*Bulbostylis barbata*	AS	6					
Cyperaceae	*Cyperus gilesii*	PS	11	6				
Cyperaceae	*Fimbristylis dichotoma*	PS	72	6	13		47	82
Cyperaceae	*Scleria sphacelata*	PS		6	7			
Droseraceae	*Drosera burmanni*	PH	6					
Euphorbiaceae	*Chamaesyce drummondii*	AH				8	27	18
Euphorbiaceae	*Euphorbia sarcostemmoides*	S	17				7	
Euphorbiaceae	*Euphorbia tannensis*	AH					13	
Fabaceae	*Indigofera oxyrachis*	S				8		
Fabaceae	*Jacksonia rhadinoclona*	S	22					
Goodeniaceae	*Goodenia atriplexifolia*	PH	17		7			
Goodeniaceae	*Goodenia havilandii*	AH					13	
Goodeniaceae	*Goodenia lunata*	AH					7	
Goodeniaceae	*Velleia glabrata*	AH					7	18
Haloragaceae	*Haloragis odontocarpa*	AH					7	
Hemerocallidaceae	*Dianella porracea*	PL					13	
Lamiaceae	*Prostanthera megacalyx*	S	11					
Lamiaceae	*Prostanthera suborbicularis*	S					7	9
Lamiaceae	*Spartothamnella puberula*	PH		6				
Lamiaceae	*Westringia rigida*	S	11					
Malvaceae	*Abutilon calliphyllum*	PH				38		

Family	Species	Life form	Barren plateau	Bendee slope	Bendee tabeland	Gidgee toeslope	Mulga tabeland	Shrubby tabeland
Malvaceae	*Abutilon fraseri*	PH		6		23		
Malvaceae	*Abutilon otocarpum*	PH		6	13		60	
Malvaceae	*Abutilon oxycarpum*	PH					13	
Malvaceae	*Hibiscus brachysiphonious*	PH				15		
Malvaceae	*Hibiscus krichkauffianus*	PH			7		20	
Malvaceae	*Hibiscus* sp. (Emerald S.L.Everist 2124)	PH		6		8	20	
Malvaceae	*Hibiscus sturtii*	PH		25		8	13	
Malvaceae	*Malvastrum americanum*	AH		6	13	38		
Malvaceae	*Melhania oblongifolia*	PH				8		
Malvaceae	*Sida* sp. (affin. trichopoda)	PH		13	7		7	
Malvaceae	*Sida aprica*	PH		50	20		7	
Malvaceae	*Sida everistiana*	PH				77		
Malvaceae	*Sida fibulifera*	PH		6		31		
Malvaceae	*Sida petrophila*	S			7			
Malvaceae	*Sida platycalyx*	PH					7	
Malvaceae	*Sida* sp. (Jericho E.J.Thompson+JER117)	PH	6	38	20	23	80	91
Malvaceae	*Sida* sp. (Laglan Station L.S.Smith 10325)	PH					7	9
Malvaceae	*Sida* sp. (Musselbrook M.B.Thomas+MRS437)	PH			7	8		
Malvaceae	*Sida trichopoda*	PH				8		
Malvaceae	*Sida* sp. ('twiggy')	PH	28	13			7	
Mimosaceae	*Acacia aneura*	T	17	13	13	15	100	55
Mimosaceae	*Acacia cambagei*	T				100		
Mimosaceae	*Acacia catenulata*	T	44	100	100	15		
Mimosaceae	*Acacia* sp. (Fermoy Road I.V.Newman 487)	T	28	6	13		7	
Mimosaceae	*Acacia ensifolia*	T		25				
Mimosaceae	*Acacia harpophylla*	T				15		
Mimosaceae	*Acacia petraea*	T	6		13			
Mimosaceae	*Acacia ramulosa*	S						55
Mimosaceae	*Acacia* sp. (affin. cana)	T				8		
Mimosaceae	*Acacia stowardii*	S	89		7		33	55
Mimosaceae	*Acacia torulensis*	S					7	9
Myoporaceae	*Eremophila arbuscula*	T		50	7			
Myoporaceae	*Eremophila bowmanii*	S		6			53	55
Myoporaceae	*Eremophila latrobei*	S	28	6	20			
Myoporaceae	*Eremophila linsmithii*	S		6		23		
Myoporaceae	*Eremophila mitchellii*	S				38		
Myoporaceae	*Eremophila oppositifolia*	S				8		
Myoporaceae	*Myoporoum montanum*	S				8		
Myrtaceae	*Corymbia blakei*	T	39	6	7			27
Myrtaceae	*Corymbia terminalis*	T					33	27
Myrtaceae	*Corymbia tessellaris*	T	11	6	7		13	18
Myrtaceae	*Eucalyptus cambageana*	T			7			
Myrtaceae	*Eucalyptus exserta*	T	6		7			
Myrtaceae	*Eucalyptus melanophloia*	T					13	9
Myrtaceae	*Eucalyptus populnea seedling*	T			7		53	18
Myrtaceae	*Eucalyptus thozetiana*	T		13	7	15	7	
Myrtaceae	*Homalocalyx polyandrous*	S	22					
Myrtaceae	*Thryptomene parviflora*	S						9
Nyctaginaceae	*Boerhavia dominii*	AH				15		9

Family	Species	Life form	Barren plateau	Bendee slope	Bendee tabeland	Gidgee toeslope	Mulga tabeland	Shrubby tabeland
Oxalidaceae	*Oxalis radicosa*	AH					7	
Poaceae	*Amphipogon caricinus*	PG	6				20	45
Poaceae	*Apophyllum anomalum*	S				15		
Poaceae	*Aristida contorta*	AG	6				7	27
Poaceae	*Aristida echinata*	PG						9
Poaceae	*Aristida holathera*	PG					7	27
Poaceae	*Aristida jerichoensis*	PG	17				7	27
Poaceae	*Aristida strigosa*	PG				8		
Poaceae	*Chloris pectinata*	AG				15		
Poaceae	*Cymbopogon refractus*	PG		6			7	
Poaceae	*Dactyloctenium radulans*	AG				8		
Poaceae	*Digitaria ammophila*	PG			7		7	
Poaceae	*Digitaria brownie*	PG						9
Poaceae	*Digitaria diminuta*	PG	6	13	20		67	45
Poaceae	*Enneapogon lindleyanus*	PG				31		
Poaceae	*Enneapogon polyphyllus*	AG	6	25		23	27	18
Poaceae	*Enteropogon acicularis*	PG		6	7	38		
Poaceae	*Eragrostis dielsii*	AG					7	
Poaceae	*Eragrostis eriopoda*	PG	6					18
Poaceae	*Eragrostis lacunaria*	PG	50	56	73	31	100	91
Poaceae	*Eragrostis macrocarpa*	PG			7		33	27
Poaceae	*Eragrostis parviflora*	AG						9
Poaceae	*Eragrostis sororia*	PG	6				7	
Poaceae	*Eriachne helmsii*	PG			7	8		
Poaceae	*Eriachne mucronata*	PG	44					9
Poaceae	*Eriachne pulchella*	AG	83		13		13	27
Poaceae	*Leptochloa decipiens*	PG					7	
Poaceae	*Monachather paradoxus*	PG					13	55
Poaceae	*Panicum effusum*	PG					47	73
Poaceae	*Paspalidium gracile*	PG		69	47	8	13	
Poaceae	*Schizachyrium fragile*	AH						9
Poaceae	*Sporobolus actinocladus*	PG				38		
Poaceae	*Sporobolus caroli*	AG		19	13	69		
Poaceae	*Sporobolus scabridus*	PG		38		15		9
Poaceae	*Thyridolepis mitchelliana*	PH	17	6	27		73	45
Poaceae	*Tragus australiense*	AG					7	
Poaceae	*Tripogon lolliiformis*	AG	78	13	33	8	47	55
Poaceae	*Urochloa gilesii*	AG			7			
Polygalaceae	*Polygala linariifolia*	PH					7	
Portulacaceae	*Calandrinia* sp. (Lumeah R.W.Purdie2168)	AH	39		13			
Portulacaceae	*Portulaca bicolour*	AH				8		
Portulacaceae	*Portulaca oleracea*	AH				23		
Portulacaceae	*Portulaca pilosa*	AH				8		
Proteaceae	*Hakea collina*	S	44					
Proteaceae	*Hakea maconochiana*	S	11					
Proteaceae	*Hakea* sp. (Mt Calder)	S			7		7	
Rhamnaceae	*Ventilago viminalis*	T			7			
Rubiaceae	*Spermacoce brachystema*	AH						18
Rubiaceae	*Synaptantha tillacea*	AH	6				7	27

Family	Species	Life form	Barren plateau	Bendee slope	Bendee tabeland	Gidgee toeslope	Mulga tabeland	Shrubby tabeland
Rutaceae	*Flindersia maculosa*	T		6		15		
Rutaceae	*Geijera parviflora*	S		25		31		
Santalaceae	*Santalum lanceolatum*	T				15		
Sapindaceae	*Alectryon oleofolium*	T		6		15		
Sapindaceae	*Atalaya hemiglauca*	T		13		8		
Sapindaceae	*Dodonaea lanceolata*	S		6				
Sapindaceae	*Dodonaea petiolaris*	S		6	7		20	9
Solanaceae	*Solanum cleistogamum*	PH					7	
Solanaceae	*Solanum ellipticum*	PH		25	27	31	53	82
Solanaceae	*Solanum esuriale*	PH					7	
Verbenaceae	*Clerodendrum floribundum*	T			7			
Zygophyllaceae	*Roepera apiculata*	AH		6		15		

<u>Appendix 6-1.</u> Species excluded from the analysis due to being more common outside study area or uncertain taxonomy. NCA = Nature Conservation Act; E, endangered; V, vulnerable, NT, near threatened; LC, locally common

Family	Species	NCA Status	Reason excluded	Western Qld records (all regions)	Notes
Asteraceae	*Brachyscome tesquorum*	NT	Other regions	2 (54)	Widespread and common in limestone and sandstone (with carbonate) habitats in Northern Territory into Western Australia (D. Albrecht, pers.comm.)
Asteraceae	*Olearia* aff. *ferresii*	LC	Taxonomy	5 (5)	Found in sheltered habitats at five locations in northern Grey and Gowan Range, over 4900km^2; total of 500 plants. Apparently distinct from *Olearia ferresii*, but taxonomic clarification required (A. Holland, pers.comm.). If distinct, meets criteria for listing as Vulnerable (D2).
Asteraceae	*Picris barbarorum*	V	Other regions	2 (15)	Known from a single population near Tambo and two 1970s records from south of Cunnamulla and near Louth; stronghold is Darling Downs grasslands, where it can be extremely abundant in some years (e.g. summer 2007) but absent or very rare for most of the time.
Boraginaceae	*Heliotropium chalcedonium*	LC	Taxonomy	1 (1)	Known only from type collection near Urandangi in 1947; searched for at numerous locations in this area and numerous *Heliotropium* samples collected. None keyed out satisfactorily, but did not match *H.chalcedonium* which has broad leaves and short hairs on top of seeds (J. Thompson, pers.comm.)
Brassicaceae	*Arabidella* sp. (Eurella S.L.Everist 3734)	LC	Taxonomy	3 (4)	4 isolated records: Muckadilla, Blackall, Eulo, Tibooburra; last collected in Queensland in 1949; specimens look very similar to *Arabidella glaucescens*.
Chenopodiaceae	*Atriplex morrisii*	V	Other regions + taxonomy	1 (9)	Patchily distributed across NT, SA and NSW, with a 1936 record from Qld (south of Eromanga) - two suspected recent collections in western Qld were not this species and one appeared to be a hybrid between *Atriplex spongiosa* and *A.lobativalvis*. Examination of specimens from other states required to resolve taxonomy; if a distinct species, surveys at sites of historical collections in NSW and SA required to assess conservation status.
Chenopodiaceae	*Chenopodium hubbardii*	LC	Taxonomy	14 (14)	Not collected since 1967; similar to *C.desertorum* - distinguished by non-fetid nature, tepals turning black and enclosing fruit + very narrow inflorescence. These characters are not clear from specimens and both characters can occur on plants within the same population. Probably not a distinct taxon.
Chenopodiaceae	*Dysphania valida*	LC	Other regions + taxonomy	2 (8)	Very close to *D.glomulifera* (key in Wilson 1984); most collections from Brigalow Belt.

Family	Species	NCA Status	Reason excluded	Western Qld records (all regions)	Notes
Chenopodiaceae	*Osteocarpum scleropterum*	LC	Taxonomy	2 (2)	Known from two old collections south of Cunnamulla. Wilson (1984) considers representatives of this species are probably of hybrid origin involving *O.acropterum* and possibly *S.calcarata* or *anisacanthoides*. The only collection in which 2-5 wings are present is type; others bear only a short wing and 1-4 tubercles.
Chenopodiaceae	*Sclerolaena blackiana*	NT	Other regions	2 (103)	Large population found in far western Qld in 2010 (30 000 plants on Ethabuka station), although had disappeared by 2012; most records from SA + scattered in NSW and NT - surveys in those states required to assess status.
Chenopodiaceae	*Sclerolaena blakei*	V	Taxonomy	1 (1)	Known only from type collection in 1936, between Boulia and Bedourie; looks very close to *S.cuneata*. 10 hours search effort failed to locate species.
Convolvulaceae	*Duperreya halfordii*	LC	Other regions	2 (11)	Most records from western NSW (Cobar, Louth, Bourke districts) + 2 Qld records (Thargomindah 1955, Cunnamulla 1972). Apparently rare at most sites but ungrazed; last NSW collection was 1987, and this species is a priority for surveys.
Cyperaceae	*Eleocharis blakeana*	NT	Other regions	2 (28)	Southern Brigalow Belt species, just into north-eastern Mulga Lands at two sites near Mungallala (common at both sites)
Cyperaceae	*Schoenus centralis*	LC	Other regions	1 (12)	Known from scattered collections in Qld, NSW, NT & WA; NT records are from springs (one population has recently been re-found); seems strange that it occurs in springs in NT and rainwater swamps in Qld (D. Albrecht, pers.comm.)
Fabaceae	*Vigna* sp. (McDonald Downs Station R.A.Perry 3416)	LC	Taxonomy	4 (5)	Taxonomically messy group, currently being worked on, but it seems *Vigna* sp. (McDonald Downs) may grade into the widespread *Vigna lanceolata* (A. Holland, pers.comm.)
Johnsoniaceae	*Corynotheca licrota*	LC	Other regions	3 (70)	Most records from southern Northern Territory (many recent records, listed as near threatened) + scattered inland NSW & SA; not found in many hours searching in western Qld and NSW, where it has only been collected once in past 25 years.
Mimosaceae	*Acacia spania*	NT	Other regions	1 (15)	Brigalow Belt/Desert Uplands species, with single isolated record from study area (Idalia National Park) (infertile specimen).
Myrtaceae	*Micromyrtus rotundifolia*	V	Other regions	1 (8)	Mostly Desert Uplands, with a single record from eastern Mulga Lands.

Family	Species	NCA Status	Reason excluded	Western Qld records (all regions)	Notes
Poaceae	*Yakirra websteri*	LC	Taxonomy	2 (2)	Looks very similar to *Panicum effusum*; searching at 11 sites close to both collections (precise locations not available for either) unsuccessful.
Surinaceae	*Cadellia pentastylis*	V	Other regions	4 (75)	Doesn't meet criteria for listing unless ongoing decline is proven, which does not seem to be the case (although past decline through landclearing is well-documented). However not assessed on basis of western Qld surveys, as study area contains only a tiny fraction of the species' total range and numbers.
Zygophyllaceae	*Roepera humillima*	LC	Other regions	2 (57)	Widspread and quite common in eastern-central South Australia; Queensland and NSW populations are eastern outliers. Locally abundant across large areas in certain seasons in Diamantina and Astrebla Downs National Parks (M. Rich, pers.comm.).
Zygophyllaceae	*Roepera rowelliae*	LC	Other regions	1 (43)	Mostly restricted to central Australia (South Australia into Northern Territory) in limestone habitats; single outlying record from south-west Qld (1971)

Reference: Wilson, P.G. 1984, 'Chenopodiaceae', in *Flora of Australia, Volume 4: Phytolaccaceae to Chenopodiaceae*, Australian Government Publishing Service, Canberra.

<u>Appendix 6-2.</u> Survey summary and assessment of threat status for 91 candidate species. Parameters which are below IUCN thresholds are bolded. SE = search effort. Category relates to re-assessment categories (Table 2 in text)

Species (Family)	**SE hours (sites)**	**SE (km^2)**	**Broad habitat (sub-habitat)**	**Extent of occurrence (area of occupancy) (km^2)**	**Population size (number of populations)**	**Extreme fluctuations?**	**1/A. Decline in numbers**	**2/B. Geographic distribution**	**3/C. Total number low AND decline predicted**	**4/D. Total number low or very restricted range**	**5/E. Extinction probability**	**NCA Status (EPBC status) (2010)**	**Assessment (2013)**	**Catgory**
Rhaphidospora bonneyana (Acanthaceae)	40 (52)	3.16	Residuals (gorges; creeklines)	**32070 (13)**	164780 (14)	No	<20%	Not eligible	Not eligible	**NT (D2)**	Not eligible	**V (V)**	**NT**	6
Xerothamnella parvifolia (Acanthaceae)	32 (75)	15.00	Residuals (gidgee toeslopes, mesas)	287260 **(240)**	7635700 (>60)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**V (V)**	LC	2
Gunniopsis sp. (Edgbaston R.J.Fensham 5094) (Aizoaceae)	5 (15)	0.11	GAB scalds (soaks)	**2.8 (0.0017)**	**198 (4)**	**Yes**	<20%	**CE (B1, B2)**	**E**	**E**	**V**	LC (LC)	**E**	3
Nyssanthes impervia (Amaranthaceae)	7 (16)	0.40	Residuals (scree slopes)	**8 (0.5)**	**16250 (2)**	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	6
Nyssanthes longistyla (Amaranthaceae)	5 (12)	0.29	Residuals (scree slopes)	**14477 (3.25)**	**<10000 (4)**	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	6
Ptilotus brachyanthus (Amaranthaceae)	20 (45)	2.00	Sandy slopes	**18500 (<10)**	**2650 (3)**	**Yes**	<20%	**E (B2)**	**V**	Not eligible	Not eligible	**E** (LC)	**E**	5
Ptilotus maconochiei (Amaranthaceae)	12 (26	1.34	Residuals (scree slopes)	81000 **(<10)**	**18000 (7)**	No	<20%	Not eligible	Not eligible	**NT (D2)**	Not eligible	**NT** (LC)	**NT**	6
Ptilotus pseudo-helipteroides (Amaranthaceae)	15 (82)	14.00	Stony plains	2344280 (15000)	1428570000 (>80)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT** (LC)	LC	2
Ptilotus remotiflorus (Amaranthaceae)	13 (70)	3.57	Residuals (kaolonite toeslopes)	141600 **(39)**	1230000 (45)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Ptilotus (Pot Jostler) (Amaranthaceae)	0.5 (1)	0.02	Residuals (kaolonite toeslopes)	**0.01 (0.01)**	**500 (1)**	No	<20%	Not eligible	Not eligible	**?V (D2)**	??	New species	**V**	6
Actinotus paddisonii (Apiaceae)	30 (70)	0.53	Mulga lands spinifex	57180 **(300)**	8800700 (13)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT** (LC)	LC	2
Eryngium fontanum (Apiaceae)	50 (200)	0.50	GAB discharge springs	**3138 (0.06)**	**6000** (56)	No	<20%	**E (B1, B2)**	**V**	**V (D2)**	Not eligible	**E (E)**	**E**	3
Rhynchharena linearis (Apocynaceae)	50 (100)	10.00	Variable	5228434 **(10)**	**<20000** (94)	No	Unknown	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	**NT**	5
Typhonium sp. (Tobermorey B.G.Thomson 2360) (Araceae)	1 (5)	1.00	Acacia georginae woodland	**4700 (100)**	**<1000 (5)**	**Yes**	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	6

Species (Family)	SE hours (sites)	SE (km^2)	Broad habitat (sub-habitat)	Extent of occurrence (area of occupancy) (km^2)	Population size (number of populations)	Extreme fluctuations?	1/A. Decline in numbers	2/B. Geographic distribution	3/C. Total number low AND decline predicted	4/D. Total number low or very restricted range	5/E. Extinction probability	NCA Status (EPBC status) (2010)	Assessment (2013)	Catgory
Hydrocotyle dipleura (Araliaceae)	94 (375)	0.94	GAB discharge springs & soaks	45344 **(0.06)**	**11400** (57)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	**V (V)**	**V**	4
Trachymene clivicola (Araliaceae)	7 (24)	0.49	Residuals (scree slopes)	129226 (**<15)**	129000 (10)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Calocephalus (Lake Huffer) (Asteraceae)	15 (50)	40.00	GAB scalds	**1945 (150)**	750000 (23)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Calocephalus sp. (Eulo M.E.Ballingall MEB2590) (Asteraceae)	29 (89)	2.99	GAB scalds	**7000 (3.2)**	**15000** (20)	**Yes**	<20%	**V (B1, B2)**	**NT**	**V (D2)**	Not eligible	**NT (LC)**	**V**	3
Calotis suffruticosa (Asteraceae)	21 (100)	1.25	Mitchell grass downs	**8 (0.001)**	**8 (1)**	**Yes**	Unknown	**E (B1, B2)**	**E**	**E**	**V**	**NT** (LC)	**E**	6
Epaltes (Bowen Downs) (Asteraceae)	8 (10)	0.49	GAB scalds	**4 (0.001)**	**500 (3)**	No	<20%	**E (B1, B2)**	Not eligible	**V (D2)**	Not eligible	New species	**E**	3
Ixiochlamys integerrima (Asteraceae)	8 (22)	0.50	Limestone (low limestone hills)	212286 **(120)**	>100 000 (20)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Pluchea (Aramac Station) (Asteraceae)	8 (10)	0.49	GAB scalds	**4 (0.001)**	**500 (2)**	No	<20%	**E (B1, B2)**	**E**	**V (D1, D2)**	Not eligible	New species	**E**	3
Rhodanthe rufescens (Asteraceae)	10 (30)	1.00	Hard mulga	**27333 (2730)**	**5000 (5)**	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT**	LC	2
Vittadinia decora (Asteraceae)	3 (10)	0.29	Sand ridges	**0.1 (0.1)**	**500 (1)**	No	<20%	Not eligible	Not eligible	**V (D1, D2)**	Not eligible	**NT**	**NT**	7
Isotoma (Elizabeth Springs) (Campanulaceae)	94 (375)	0.94	GAB discharge springs	**0.09 (0.09)**	**500 (5)**	No	<20%	**E (B1, B2)**	**E**	**V (D1, D2)**	**V**	LC (LC)	**E**	3
Isotoma sp. (Myross R.J.Fensham 3883) (Campanulaceae)	15 (58)	0.15	GAB discharge springs	**27560 (0.0003)**	**3000** (15)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	4
Atriplex fissivalvis (Chenopodiaceae)	10 (40)	2.00	Stony plains + residuals	631465 (4000)	4000000 (35)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT** (LC)	LC	2
Atriplex lobativalvis (Chenopodiaceae)	25 (100)	2.00	Dunefields (claypans) + floodplains	236346 **(1000)**	400000000 (62)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT** (LC)	LC	2
Maireana cheelii (Chenopodiaceae)	14 (40)	1.24	Floodplains	**450 (45)**	150000 (10)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC **(V)**	LC	1
Maireana lanosa (Chenopodiaceae)	25 (50)	20.00	Dunefields	873400 **(400)**	5000000 (11)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1

Species (Family)	**SE hours (sites)**	**SE (km^2)**	**Broad habitat (sub-habitat)**	**Extent of occurrence (area of occupancy) (km^2)**	**Population size (number of populations)**	**Extreme fluctuations?**	**1/A. Decline in numbers**	**2/B. Geographic distribution**	**3/C. Total number low AND decline predicted**	**4/D. Total number low or very restricted range**	**5/E. Extinction probability**	**NCA Status (EPBC status) (2010)**	**Assessment (2013)**	**Catgory**
Osteocarpum pentapterum (Chenopodiaceae)	5 (25)	0.50	Stony plains	217300 (15000)	200000000 (15)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Sclerolaena walkeri (Chenopodiaceae)	40 (100)	12.00	Floodplains	271360 **(>2000)**	24015000 (35)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**V (V)**	LC	2
Austrobryonia argillicola (Curcurbitaceae)	40 (130)	3.00	Mitchell grass downs	159830 (4700)	7000000 (18)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**E (E)**	LC	2
Fimbristylis sp. (Elizabeth Sps. R.J.Fensham 3743) (Cyperaceae)	75 (300)	0.75	GAB discharge springs	206500 **(0.0875)**	**3000** (33)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	4
Eriocaulon aloefolium (Eriocaulaceae)	50 (200)	0.50	GAB discharge springs	**0.2 (0.05)**	**2588 (1)**	No	**V**	**CE**	**E**	**V (D2)**	**V**	**E (CE)**	**E**	3
Eriocaulon carsonii (Eriocaulaceae)	250 (1000)	2.50	GAB discharge springs	1150900 **(1)**	212000 (90)	No	**V**	**E (B2)**	Not eligible	**V (D2)**	Not eligible	**E (E)**	**E**	3
Eriocaulon giganticum (Eriocaulaceae)	50 (200)	0.50	GAB discharge springs	**0.001 (0.001)**	**263 (1)**	No	**V**	**CE**	**E**	**V (D2)**	**V**	**E (CE)**	**E**	3
Euphorbia sarcostemmoides (Euphorbiaceae)	45 (125)	9.56	Residuals (barren plateaux)	899334 **(200)**	440000 (46)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**V (V)**	LC	2
Ricinocarpos crispatus (Euphorbiaceae)	27 (23)	3.73	Residuals (gorges; creeklines)	**2440 (20)**	429500 (20)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Indigofera haematica (Fabaceae)	7 (25)	0.99	Residuals (barren plateaux)	93567 **(102)**	183600 **(9)**	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Indigofera oxyrachis (Fabaceae)	20 (33)	2.39	Residuals (gidgee toeslopes, mesas)	**6871 (31)**	50000 **(8)**	No	<20%	Not eligible	Not eligible	**NT (D2)**	Not eligible	**V** (LC)	**V**	6
Swainsona similis (Fabaceae)	8 (26)	0.50	Mulga	?? (??)	??	Unknown	Unknown	??	Not eligible	??	Not eligible	LC (LC)	**DD**	7
Goodenia angustifolia (Goodeniaceae)	6 (30)	0.53	Stony plains	160250 (10000)	198000 (11)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT (LC)**	LC	2
Goodenia atriplexifolia (Goodeniaceae)	41 (103)	2.02	Residuals (barren plateaux)	56130 **(202)**	2520 000 (30)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Myriophyllum artesium (Haloragaceae)	175 (700)	1.75	GAB discharge springs	578810 **(1)**	100000 (90)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	**E** (LC)	**V**	4
Caesia chlorantha (Johnsoniaceae)	36 (150)	2.00	Mitchell grass downs	536000 (**3500)**	27500000 (16)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Utricularia ameliae (Lentibulariaceae)	15 (58)	0.15	GAB discharge springs	**0.09 (0.025)**	**500 (1)**	No	<20%	**E (B1, B2)**	**E**	**V (D1, D2)**	**V**	LC (LC)	**E**	3

Species (Family)	**SE hours (sites)**	**SE (km^2)**	**Broad habitat (sub-habitat)**	**Extent of occurrence (area of occupancy) (km^2)**	**Population size (number of populations)**	**Extreme fluctuations?**	**1/A. Decline in numbers**	**2/B. Geographic distribution**	**3/C. Total number low AND decline predicted**	**4/D. Total number low or very restricted range**	**5/E. Extinction probability**	**NCA Status (EPBC status) (2010)**	**Assessment (2013)**	**Catgory**
Utricularia fenshamii (Lentibulariaceae)	250 (1000)	2.50	GAB discharge springs	920900 **(<1)**	**5000** (>60)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	4
Sida argentea (Malvaceae)	10 (40)	1.20	Riparian	156000 **(38)**	**5000 (8)**	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	5
Sida asterocalyx (Malvaceae)	18 (44)	1.72	Residuals (barren plateaux)	30284 **(180)**	1017000 (25)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Acacia ammophila (Mimosaceae)	6 (20)	100.00	Dunefields; gidgee woodlands	**5970 (320)**	**17500 (3)**	No	**NT**	**V (B1, B2)**	**NT**	**NT (D2)**	Not eligible	**V (V)**	**V**	5
Acacia crombiei (Mimosaceae)	10 (40)	4.00	Wooded downs + basalt	**34000 (1000)**	**20000** (15)	No	**NT**	**V (B2)**	Not eligible	Not eligible	Not eligible	**V (V)**	**V**	5
Acacia peuce (Mimosaceae)	3 (3)	40.00	Plains	74350 **(400)**	76000 (3)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	**V (V)**	**V**	6
Acacia philoxera (Mimosaceae)	3 (10)	0.60	Residuals	**5 (0.6)**	**4400 (4)**	No	<20%	Not eligible	Not eligible	**V (D1, D2)**	Not eligible	New species	**V**	6
Acacia sp. (aff. cana) (Mimosaceae)	15 (40)	2.00	Residuals (creeklines; gorges)	**20000 (400)**	1600000 (40)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Acacia sp. (Ambathala C.Sandercoe 624) (Mimosaceae)	10 (30)	0.50	Residuals (creeklines; gorges)	**3980 (10)**	**10000** (15)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	6
Acacia sp. (Fermoy Road I.V.Newman 487) (Mimosaceae)	28 (77)	3.33	Residuals (barren plateaux)	46700 **(250)**	700000 (30)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Glinus orygioides (Molluginaceae)	13 (50)	2.00	Dunefields (claypans) + floodplains	584600 **(700)**	65000000 (25)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Eremophila arbuscula (Myoporaceae)	15 (40)	5.00	Residuals (gorges; bendee slopes)	63900 **(450)**	9000000 (55)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Eremophila sp. (Eromanga E.R. Anderson 5069) (Myoporaceae)	2 (10)	0.25	Residuals (creeklines; gorges)	**33 (1)**	**<1000 (5)**	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	New species	**V**	6
Eremophila sp. (Opalton V.J. Neldner+2619) (Myoporaceae)	5 (10)	5.00	Residuals (barren plateaux)	**220 (50)**	170000 **(8)**	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Eremophila stenophylla (Myoporaceae)	7 (20)	9.80	Residuals (gidgee toeslopes)	54800 **(500)**	41500 (20)	No	<20%	**V (B2)**	Not eligible	Not eligible	Not eligible	LC (LC)	**V**	5

Species (Family)	**SE hours (sites)**	**SE (km^2)**	**Broad habitat (sub-habitat)**	**Extent of occurrence (area of occupancy) (km^2)**	**Population size (number of populations)**	**Extreme fluctuations?**	**1/A. Decline in numbers**	**2/B. Geographic distribution**	**3/C. Total number low AND decline predicted**	**4/D. Total number low or very restricted range**	**5/E. Extinction probability**	**NCA Status (EPBC status) (2010)**	**Assessment (2013)**	**Catgory**
Eremophila tetraptera (Myoporaceae)	50 (20)	10.00	Downs; residuals (gypseous soils)	**8500 (400)**	600000 (20)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**V** (LC)	**V**	6
Kunzea (Forster 35406) (Myrtaceae)	4 (8)	0.20	Residuals (creekline)	**0.01 (0.006)**	**32 (1)**	No	<20%	Not eligible	Not eligible	**E**	**V**	LC (LC)	**E**	6
Melaleuca kunzeoides (Myrtaceae)	10 (50)	1.00	Residuals (Tertiary springs)	**4.7 (0.02)**	**617 (6)**	No	<20%	Not eligible	Not eligible	**V (D1, D2)**	Not eligible	**V (V)**	**V**	6
Melaleuca sp. (Mt Marlow M.E. Ballingall MEB2737) (Myrtaceae)	0 (0)	0.00	Residuals (gidgee toeslopes)	**2 (2)**	**?500 (1)**	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	LC (LC)	**V**	6
Thryptomene hexandra (Myrtaceae)	20 (200)	20.00	Residuals	443000 (5000)	25000000 (>100)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT** (LC)	LC	2
Nymphaea georginae (Nymphaeaceae)	1.5 (5)	1.00	Wetlands (waterholes)	53170 **(1.5)**	30000 (30)	No	<20%	Not eligible	Not eligible	**?NT (D2)**	Not eligible	LC (LC)	**DD**	7
Phyllanthus involutus (Phyllanthaceae)	12 (40)	1.90	Hard mulga + residuals	**11000 (1500)**	8000000 (15)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Sauropus ramosissimus (Phyllanthaceae)	45 (145)	3.30	Residuals (barren plateaux; gorges; boulder-fields)	1748980 **(500)**	>100000 (35)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Austrochloris dichanthioides (Poaceae)	20 (80)	3.00	Mulga	404140 (5000)	11000000 (23)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Austrostipa blakei (Poaceae)	6 (25)	0.30	Sandy red earths & light clays	**6700 (5)**	**1500 (3)**	Unknown	<20%	Not eligible	Not eligible	**NT (D1, D2)**	Not eligible	LC (LC)	**DD**	7
Chloris sp. (Edgbaston R.J.Fensham 5694) (Poaceae)	17 (20)	0.89	GAB scalds	**0.3 (0.1)**	**400 (2)**	No	<20%	**E (B1, B2)**	**E**	**V (D1, D2)**	**V**	LC (LC)	**E**	3
Digitaria hubbardii (Poaceae)	12 (65)	0.50	Mulga	**25500** (6500)	75000000 (35)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Eragrostis fenshamii (Poaceae)	59 (235)	2.35	GAB discharge springs	**34100 (0.2)**	**4950** (40)	No	<20%	**V (B1, B2)**	**V**	**V (D2)**	Not eligible	LC (LC)	**V**	4
Iseilema calvum (Poaceae)	32 (127)	2.40	Mitchell grass downs, depressions	119400 **(1000)**	5300000 (13)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1

Species (Family)	**SE hours (sites)**	**SE (km^2)**	**Broad habitat (sub-habitat)**	**Extent of occurrence (area of occupancy) (km^2)**	**Population size (number of populations)**	**Extreme fluctuations?**	**1/A. Decline in numbers**	**2/B. Geographic distribution**	**3/C. Total number low AND decline predicted**	**4/D. Total number low or very restricted range**	**5/E. Extinction probability**	**NCA Status (EPBC status) (2010)**	**Assessment (2013)**	**Catgory**
Spathia neurosa (Poaceae)	15 (58)	0.54	Mitchell grass downs	791300 **(>2000)**	**300 (6)**	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	**DD**	7
Sporobolus pamelae (Poaceae)	94 (375)	3.75	GAB discharge springs	**38060 (0.52)**	**10200** (	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	**E** (LC)	**V**	4
Sporobolus partimpatens (Poaceae)	250 (1000)	5.00	GAB scalds	547300 **(500)**	1200000 (37)	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT (LC)**	LC	2
Urochloa atrisola (Poaceae)	22 (81)	1.00	Mitchell grass downs	51700 **(2600)**	700000000 (19)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Calandrinia sp. (Lumeah R.W.Purdie 2168) (Portulacaceae)	39 (97)	6.43	Residuals (barren plateaux)	61240 **(500)**	800 000 000 (66)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Grevillea kennedyana (Proteaceae)	8 (15)	1.50	Residuals (mesa slopes)	**1460 (12)**	**>13000** (12)	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	**V (V)**	**V**	6
Hakea maconochieana (Proteaceae)	35 (73)	2.95	Residuals (barren plateaux)	**16150 (45)**	52000 (13)	No	<20%	**V (B1, B2)**	Not eligible	Not eligible	Not eligible	**V** (LC)	**V**	6
Hakea (Gowan Range) (Proteaceae)	12 (50)	0.50	Residuals	**50 (0.1)**	**36 (2)**	No	<20%	Not eligible	**V**	**V (D2)**	Not eligible	New species	**V**	6
Oldenlandia spathulata (Rubiaceae)	9 (33)	0.34	Mitchell grass downs	**200 (40)**	1459000 **(6)**	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**E** (LC)	LC	2
Dodonaea intricata (Sapindaceae)	15 (32)	1.55	Residuals (barren plateaux)	**1165 (13)**	92000 **(9)**	No	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Elacholoma hornii (Scrophulariaceae)	10 (40)	0.50	Wetlands	2083000 (5000)	>1000000 (40)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	**NT (LC)**	LC	1
Peplidium sp. (Edgbaston R.J.Fensham 3341) (Scrophulariaceae)	94 (375)	3.75	GAB discharge springs	**5.3 (0.12)**	**2400** (24)	No	<20%	**E (B1, B2)**	**E**	**V (D2)**	Not eligible	LC (LC)	**E**	3
Solanum pisinnum (Solanaceae)	15 (30)	0.30	Mulga	**3200 (100)**	>500000 **(8)**	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1
Solanum unispinum (Solanaceae)	0 (0)	0.00	Residuals	**8140 (5)**	**35 (5)**	No	<20%	Not eligible	Not eligible	**V (D2)**	Not eligible	New species	**V**	6
Solanum versicolor (Solanaceae)	10 (50)	0.50	Soft mulga	**8460 (550)**	10000000 (11)	**Yes**	<20%	Not eligible	Not eligible	Not eligible	Not eligible	LC (LC)	LC	1

Appendix 6-3. Example species nomination form

Species nomination form and guidelines for adding or changing the category of a native species listing under the Queensland Nature Conservation Act 1992 (NCA); example form for *Sclerolaena walkeri*. Forms have been submitted to the Threatened Species Committee for all species where a change of status is recommended based on survey data.

General notes

The purpose of this document is to nominate a species for assessment under the NCA by the Department of Environment and Resource Management Species Technical Committee (STC) for its consideration and subsequent advice to the Minister for Climate Change and Sustainability.
Please use one nomination form for each species. The form may be submitted electronically, however the original, signed, hard copy must also be lodged. Lodgement instructions are provided at the end of the form. The STC will not consider nominations submitted in any other format.
Each section of the form needs to be completed with as much detail as possible, and indicate when there is no information available. Identify your references/ information sources, document reasons and supportive data. Indicate the quality of facts/information, for example was it based on research or anecdotal data; on observed data or estimated or inferred from data; or suspected to be the case. Identify confidential material and explain the sensitivity
The STC will not consider incomplete nominations or nominations with insufficient information. Your nomination will be returned to you if inadequate information is provided.
Your nomination must be supported with referenced summaries of relevant information from the scientific literature. Full bibliographic details are to be provided. The opinion of appropriate scientific experts may also be cited, provided they authorise you to do so. The names of the expert(s), their qualifications and full contact details must also be provided if they are cited.

The STC assesses nominations against the IUCN Red List Categories and Criteria (version 3.1) for the categories of extinct in the wild, endangered, vulnerable, near threatened and least concern. The IUCN updates its red list guidelines regularly and the STC uses the most recent version (version 8.0). This form will be updated in accord with revisions of IUCN criteria, if necessary. A full description of the IUCN categories and criteria can be found in: IUCN 2001. IUCN Red List Categories: Version 3.1. Prepared by the IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. http://www.iucnredlist.org/documents/redlist_cats_crit_en.pdf http://www.iucnredlist.org/documents/RedListGuidelines.pdf .

- Species - applies to the entity nominated under the *Nature Conservation Act*
- Population – refers to populations within a species or total population numbers for a species.

Section 1. Summary

1.1 Scientific and common name of species (or subspecies)
Sclerolaena walkeri **(C.T.White) A.J.Scott**
1.2 If the species is not conventionally accepted, please provide: • a taxonomic description of the species in a form suitable for publication in conventional scientific literature. State where this description has been submitted for publication; or • evidence that a scientific institution has a specimen of the species and a written statement signed by a person who is a taxonomist with relevant expertise (has worked, or is a published author, on the class of species nominated) that the species is new. Details of the qualifications and experience of the taxon expert need to be provided. For a specimen lodged at a museum or herbarium, state where the specimen is held, the collector name, collection date and collection/voucher number.
Accepted.
1.3 If a population is being nominated, justify why the population should be considered separately from the species as a whole. This will generally require evidence why the nominated population is considered genetically distinct and/or geographically separate and/or severely threatened in comparison with all other populations of the species.
1.4 Please provide a description of the species or population that is sufficient to distinguish it from other species or populations.
Growth habit: short-lived perennial forb to 30cm high *Leaves:* slender, fleshy and sparsely woolly when young, becoming glabrous with maturity *Flowers:* tiny, borne singly in the leaf axils, sparsely cottony with five stamens *Fruiting bodies:* very distinctive, with numerous small 'spines' emerging from a pumpkin-shaped, conspicuously-ribbed perianth. Each fruit is about 1.5mm high by 2.5mm wide (excluding spines), with the upper third narrowed into a disc-like apex, from which the spines emerge

Does not closely resemble any other species of *Sclerolaena* (or any other species in the Chenopod family). Full description provided in Wilson (1984) and Department of Environment and Water Resources (2007).
1.5 Current conservation status under Nature Conservation Act 1992 and the EPBC Act
NCA: Vulnerable   EPBC: Vulnerable
1.6 Proposed conservation status under the Nature Conservation Act 1992 and the EPBC Act
NCA: Least Concern   EPBC: Least Concern
1.7 IUCN Criteria under which the species is eligible for listing. The species should be judged against the criteria described in Attachment B: Categories and criteria used for assessing the status of species. The categories for extinct in the wild, endangered, vulnerable and near threatened use the most recent version of IUCN criteria.
None.

Section 2. Species ecology/biology

2.1 Is this species conventionally accepted? If not, explain why. Is there any controversy on the taxonomy?
Accepted.
2.2 Give a brief description of the species': appearance, including size and/or weight, and sex and age variation if appropriate; social structure and dispersion (e.g. solitary/clumped/flocks)
Short-lived perennial forb to 30cm high; blue-green foliage, densely woolly when young; plants fruit when young and single-stemmed and all plants tend to be laden with small pumpkin-shaped fruits with a crown of tiny non-spiny appendages.
2.3 Describe the species' habitat (e.g. aspect, topography, substrate, climate, forest type, associated species, sympatric species).
Seasonally-inundated floodplains and inter-channel areas, usually in open gidgee/yapunyah woodlands on grey cracking clay on the Paroo and Bulloo Rivers. Seems to prefer slight drainage depressions within this habitat, such as bluebush swamp, tabledrains, tracks etc, and slightly scalded bare areas. Commonly co-occurring species include *Atriplex spongiosa, Eragrostis australasica, Paspalidium jubiflorum, Panicum laevinode, Eragrostis parviflora, Minuria integgerima, Alternanthera nodiflora, Streptoglossa adscendens, Sporobolus mitchellii* and other *Sclerolaena* species. Also occasional in open herbfields with scattered Mitchell grass on Bulloo floodplain. At one site between Thargomindah and Toompine it was abundant on the slope above a creek channel. On Eyre Creek floodplain, it grows on deeply-cracking grey clay in sparse *Chenopodium auricomum/Acacia stenophylla.Muehlenbeckia florulenta* shrubland amongst annual flood herbage (including *Ipomoea lonchophylla, Echinochloa colona, Sesbania cannabina*). On the Diamantina floodplain, it was found in open *Eremophila bignoniflora/Chenopodium auricomum* low shrubland on brown cracking clay and an open alluvial plain between the Diamantina River and Lake Billyer. The Cooper population was found on cracking clay herbfield east of Windorah. Lake Mueller north of Aramac is an ephemeral lake, supporting open shrubland dominated by *Eremophila bignoniflora*.
2.4 What is the species' generation length? Note: Generation length is the average age of parents of the current cohort (i.e. newborn individuals in the population).
Short-lived, but can function as a perennial (perhaps up to 3 years) in good seasons.
2.5 Is there any other information regarding the species ecology or biology relevant to a conservation status assessment?
No.

Section 3. Conservation status

3.1 Describe the species' distribution in Australia and attach a map of known localities. Please include details of which Natural Resource Management and IBRA Bioregions the species occurs in.
South-western Queensland and northern New South Wales. Between 2006 and 2010, it was common on the Paroo River from south of Eulo to just south of the NSW border and the Bulloo River from Toompine to Bulloo Downs, with two records from the Diamantina floodplain (Brighton Downs and Diamantina NP, both south of L.G. Walker's original 1941 record from near the junction of the Diamantina and Mackunda Creek) and isolated records on Eyre Creek south of Bedourie, the Cooper floodplain north-east of Windorah and Lake Mueller north of Aramac. Many other locations along these floodplains were searched and the species not found. Searching in similar habitat on the Warrego and Culgoa floodplains to the east did not find the species. The Paroo and most of the Bulloo records are in the Mulga Lands IBRA and South West NRM regions; the Bulloo records south of Thargomindah, the Cooper, Eyre Creek and Diamantina records are in the Channel Country IBRA and Desert Channels NRM region, and the Lake Mueller record is in the Desert Uplands IBRA and Desert Channels NRM regions. Attached map also shows unsuccessful search effort.
3.2 What is the species' total extent of occurrence (in km^2) (see Attachment A)
Extent of occurrence is 271 360 km^2.
3.3 What is the species' total area of occupancy (in km^2) (see Attachment A)
The area of occupancy is at least 2000 km^2.
3.4 What is the species' total population size in terms of number of mature individuals?
Total population size fluctuates with prevailing seasonal conditions, so any estimate represents a snapshot in time (as discussed below in section 3.7). The estimates below relate to abundance/population size in 2007, when the species was abundant across large areas of the Bulloo and Paroo floodplains. It ranged from dominant (e.g. along old powerline between Eulo and Hungerford) to scattered/rare at individual sites. A total of 180 000 plants were found on the Paroo from April to

September 2007, including >150 000 plants across about 10ha in a bluebush swamp near Caiwarra Waterhole on Currawinya National Park. Total area of habitat (Farnham Plains to Talyealye) = 600 km^2; total area searched = 6 km^2 (1% of potential habitat). So total population is estimated at 18 million plants. 20 000 were found on the Bulloo over this same period. Total area of habitat from Bulloo Downs to Toompine) = 1500 km^2; 5 km^2 searched (0.33% of potential habitat). So total population estimated at 6 million plants. These figures are obviously very rough, but serves to illustrate that there were tens of millions of individuals on these two floodplains in 2007.

The populations recorded on Eyre Creek (500 plants), the Diamantina (200 + 100 plants), Cooper (10 plants) and Lake Mueller (10 000 plants) are very isolated and searching in areas of similar habitat nearby did not find any further populations. Thus total population estimates are not extrapolated from this data, despite the fact that only a tiny fraction of huge expanses of potential habitat along these river systems was searched and it is highly likely that there are numerous other populations.

3.5 How many locations do you consider the species occurs in and why? Where are these located?
Note: The term 'location' defines a geographically or ecologically distinct area.

The species was recorded at 34 sites: 12 on Paroo River, 17 on Bulloo, two on the Diamantina and one each on Eyre Creek, Cooper Creek and Lake Mueller. Each site was separated from other sites by at least 1 km, but all are probably part of the same populations given they occur on floodplains and seed is transported by floodwaters.

3.6 For flora, and where applicable, for fauna, detail the location, land tenure, survey date, estimated number of individuals and area of occupancy. This is optional for taxa nominated as near threatened or least concern. Summary distribution information such as a map and list of localities should be provided for taxa nominated as near threatened or least concern.

In the table below, where a site has been visited multiple times, abundance and area of occupancy are summarised for each visit, demonstrating the temporal dynamics of the species.

Location	**Land tenure**	**Date of most recent survey**	**Number of individuals at location and area of occupancy**
Near Manda Page's alluvial site on old stock route off northern boundary, Currawinya National Park	National Park	01/10/2013	Abundant from March to August 2007 (average 2 plants/m2 over at least 0.5km2/500000m2 = 1 000 000 plants), but rare at site in four visits between March 2008 and October 2013
Eulo Town Common, approximately 1.8km west of town on Thargo road	Town common (grazed)	02/10/2013	Locally common (>1000 plants over 0.01km2 in April2007; has been scattered or absent during five visits between 2008 and 2013
Ourimperee Waterhole, Currawinya National Park	National Park	2/12/2012	Scattered along 60m walked, about 50m from waterhole; about 30 plants seen in April 2011; absent in December 2012
Near Corni Paroo Waterhole campground sign, Currawinya National Park	National Park	24/10/2012	Scattered plants in from April 2007-February 2011 (about 50 seen at site); absent in October 2012
Tarko, Hungerford-Eulo road	Leasehold grazing	1/10/2013	Scattered throughout woodland, but forms dominant groundcover over a wide area to east of the road (particularly where trees cleared for old powerline); >10 000 plants in population; absent during three visits from April 2011 to October 2013
Eulo - Hungerford rd, approx 500m from Springvale turnoff	Leasehold grazing	1/10/2013	Scattered (7 plants seen in 800m2) in April 2007; absent at site when visited in May 2010, September 2011 and October 2013
Caiwarro Waterhole, Currawinya National Park	National Park	2/10/2013	Abundant across bluebush swamp - estimated 200 000-300 000 plants present between 2006 and December 2010; has been scattered at low densities at site since this time
3 Mile Crossing (Carwarra Creek), Hungerford-Eulo road north of Currawinya homestead	National Park	1/10/2013	Average density 180 plants/m2, >20 000 plants in population in July 2007; has been scattered or absent from the site in seven visits between 2008 and 2013
6 Mile crosing, southern boundary of CNP, off Hungerford-Thargomindah Road	National Park	4/12/2012	Average density 27 plants/100m2, totalling >2000 plantsin July 2007; has been rare or absent from the site during four visits between March 2008 and December 2012)
Talyalyeae, south of Hungerford; western side of Paroo River	Leasehold grazing	5/07/2007	Locally common - at least 1000 plants over 0.01km2
Paroo River floodplain, about 5km north of Hungerford, Currawinya NP	National Park	1/04/2011	Rare – two plants seen around perimeter of claypan; only ones seen in 1 hour walking

Farnham Plains, mud spring area near southern boundary	Leasehold grazing	22/10/2012	Patchily abundant, mostly on bare areas; >2000 plants in 0.01km2 area at site
Picarilli; beside main Thargomindah-Bulloo Downs road	Leasehold grazing	05/06/2009	Locally common - 500 plants over 200m x 20m area - stops abruptly on harder-setting scald
Bulloo River road, approx 3.5 km SE of Kiandra Homestead	Leasehold grazing	9/06/2013	Scattered in tabledrain - 100 plants over 0.005km2
South of Thargomindah	Town common (grazed)	9/06/2013	Scattered as single plants - 3 found; none found in October 2011 or June 2013
South of Thargomindah	Town common (grazed)	9/06/2013	Common on roadside + scattered throughout woodland; 500 plants counted over 0.01km in September 2007; 50 in October 2011; 250 in June 2013
Bullo Downs Road, south of Thargomindah	Leasehold grazing	9/06/2013	Scattered - 50 plants in 2000m2 in September 2007; 12 in October 2011
Bullo Downs Road, south of Thargomindah	Leasehold grazing	1/10/2011	Scattered; commonly associated with yapunyah trees and log patches; 400 plants seen in September 2007 and June 2009 in 1000m2; 20 and 30 in October 2011 and June 2013 respectively
Thargomindah Town Common, just east of town	Town common (grazed)	9/06/2013	Scattered to abundant - >100 000 plants over 2km2 surveyed in September 2007; has remained scattered to patchily abundant since this time
Thargomindah-Toompine River Road	Leasehold grazing	9/06/2013	Common but patchy throughout swampy area, mostly occurring in patches of small/young plants in September 2007; absent in October 2011; patchily abundant seedlings in June 2013
Thargomindah-Toompine River Road	Leasehold grazing	11/09/2007	Only occasional walkeri in 2007 and 2011
Bulloo River rd approx 8.2 km NNW Autumn Vale HS	Leasehold grazing	9/06/2013	Locally common in April 2007 - 200 seen in 400m2; still scattered in October 2011 and June 2013 (50/400m2)
Thargomindah-Toompine River Road	Leasehold grazing	9/06/2013	Dominant or co-dominant over quite a large area, including downstream side of crossing and bare areas leading down to channel - >10 000 plants over 0.02km2 in September 2007; only scattered plants in June 2013 (35 seen in 2400m2)
Thargomindah-Toompine River Road	Leasehold grazing	2/10/2011	Scattered - average density of 5 plants/100m2 over 0.01km2; only one live plant seen at site in October 2011
Thargomindah-Toompine River Road	Leasehold grazing	2/10/2011	Common (200 plants/800m2 in Sept 2007); scattered (9 plants found in 1000m2) in October 2011
Bulloo River rd approx 6 km NE of Karwalke HS	Leasehold grazing	9/06/2013	Locally very common - 1000 plants seen in 0.01km2 in April 2007; occasional plants only in October 2011 and June 2013
Thargomindah-Toompine River Road	Leasehold grazing	2/10/2011	Locally very common - 1000 plants seen in 0.01km2 in Sept 2007; scattered (total of 40 plants seen) in Oct 2011
Thargomindah-Toompine River Road	Leasehold grazing	2/10/2011	Scattered - average density of 5 plants/100m2 over 0.01km2; none seen in October 2011
Thargomindah-Toompine River Road	Leasehold grazing	2/10/2011	Common at point; mostly scattered throughout swamp in Sept 2007 (average density 30 plants/m2; 200 plants total); none seen in Oct 2011
Northern end of Lake Mueller, Edgbaston	Private conservation (Bush Heritage Australia)	11/04/2012	Abundant - mass regeneration with 6 inches of rainwfall 5 weeks ago; 130 plants along 50m transect - would be >5000 of plants over lake, but patchy; has fluctuated in abundance since first observed in 2009
Cluny, about 2km south of Glengyle homestead along Eyre Creek	Leasehold grazing	06/04/2008	Abundant over small area (100 plants) but uncommon (12 plants found in 15 minutes searching) in July 2010
Diamantina National Park, about 1km south of homestead	National Park	16/05/2009	Locally common over small area - 200 plants in 0,005km2
Lake Billyer area, Brighton Downs	Leasehold grazing	22/04/2009	Scattered over small area; not found in other areas searched

Coniston, Hammond Downs road	Leasehold grazing	15/07/2010	Uncommon - only 10 plants seen; not found elsewhere

3.7 Is the species' distribution severely fragmented? If so, what is the cause of this fragmentation? Note: Severely fragmented refers to the situation in which increased extinction risk to the taxon results from most individuals being found in small and relatively isolated populations (in certain circumstances this may be inferred from habitat information). These small populations may go extinct, with a reduced probability of recolonisation
No – occurs on floodplains and fruiting bodies float so are transported by floodwaters, in effect connecting populations occurring across the same river system.
3.8 Does the species undergo extreme natural fluctuations in population numbers, extent of occurrence or area of occupancy? To what extent and why? Note: Extreme fluctuations can be said to occur in a number of taxa when population size or distribution area varies widely, rapidly and frequently, typically with a variation greater than one order of magnitude (i.e. a tenfold increase or decrease).
Sclerolaena walkeri undergoes extreme natural fluctuations in response to rainfall and flooding, as documented in the table in section 3.6 above. The species was first collected on the Diamantina River in 1941, and was collected on the Bulloo River in 1964. In the mid-1990s, it was grown from a soil seedbank sample by Manda Page on Currawinya National Park, but was not recorded in the standing vegetation at this site between 1992 and 1997. From October 2006 to December 2008 (when all sites went under water in a flood event), *Sclerolaena walkeri* was abundant across large areas of the Paroo floodplain, including at this site. Inundation killed all existing plants in December 2008, but seedlings germinated at most sites, however in very low densities compared to pre-flooding. Through 2009, it persisted at low densities at all Paroo sites, and was only abundant at Caiwarro bluebush swamp on Currawinya, where there had been two major germination events. Sites were revisited again in February 2011, and the species was scattered in low densities at most sites but still quite common at Caiwarro, and by September 2011 was in low densities and almost unrecognizable at Caiwarro swamp. From October to December 2012, only one plant was found across six Paroo River sites revisited, and no plants found in an hour searching at Caiwarro swamp. In October 2013, it was again scattered in very low densities at most sites, including Caiwarro. *Sclerolaena walkeri* was abundant on the Bulloo floodplain between Toompine and Thargomindah in 2007-2008. By October 2011, its abundance and vigour were drastically reduced at all sites, although it was still present at 15 of 21 sites revisited. However, only at three was it sufficiently common and recognizable to have been detected by a botanist who was not specifically searching for the species (most plants were dead stems with fruits lying on the ground). In June 2013, it was abundant at sites near Thargomindah but rare or absent at sites further north where there had not been late autumn/early winter rainfall. Ongoing monitoring will provide further information on the population dynamics of this enigmatic burr. However, its apparent rarity until 2006 is probably due to a combination of its 'boom-bust' life history and low collection effort, which mean that the chances of a collector's visit coinciding with a rare boom event are low (Silcock et al. 2011).
3.9 What data are there to indicate past trends in the species' population size, distribution, extent or quality of habitat? (if available, include data that indicates the percentage decline over the past 10 years or 3 generations whichever is longer)?
There is no data to indicate declines or changes in the species' population size, distribution, extent or quality of habitat in Queensland.
3.10 What data are there to indicate future changes in the species' population size, distribution, extent or quality of habitat? (if available, include data that indicates the percentage decline over 10 years or 3 generations whichever is longer (up to a maximum of 100 years in the future) where the time period is a continuous period that may include a component of the past?
There is no indication of future long-term changes in these parameters, despite natural fluctuations discussed in Section 3.8.
3.11 Has the species been reasonably well surveyed? Is the species' current known distribution and/or population size likely to be its actual distribution and/or population size?
The species has been well surveyed between 2007 and 2010; the current known distribution is thus likely to be its actual distribution, although population size will fluctuate substantially as discussed above. The floodplains of the Paroo/Cuttaburra systems were not searched during good seasons/after flooding, and it is possible that the species' distribution extends further into NSW.
3.12 For species considered eligible for listing as extinct or extinct in the wild, please provide details of the most recent known collection, or authenticated sighting of the species in the wild and whether additional populations are likely to exist.

4. **Threats and threat abatement**

4.1 Identify past, current and future threats indicating whether they are actual or potential. For each threat describe: a. how and where it impacts on this species b. what its effect has been so far (indicate whether it is known or suspected; does it only affect certain populations) c. what is its expected effect in the future (is the threat only suspected; does it only affect certain populations)

Sclerolaena walkeri is listed as Vulnerable, as was only known from L.G. Walker's type collection in the early 1940s, and a single record from the Bulloo River in 1964. However, surveys have shown it to be abundant across large areas of floodplain, at least in certain seasons, with no threats to its persistence. It is only grazed in areas with very high total grazing pressure, and then sparingly, although does appear to be more palatable than other co-occurring Chenopod species such as *Atriplex spongiosa* and *S. muricata*. However, given that plants produce fruits when very young, and that most populations were completely ungrazed, grazing is not regarded as a threat to *Sclerolaena walkeri*.
4.2 Where possible, provide information on threats for each occurrence/location. This is optional for taxa nominated as near threatened or least concern. Summary information should be provided for taxa nominated as near threatened or least concern.
Not applicable (see section 4.1 above).
4.3 Identify and explain any additional biological characteristics particular to the species that are threatening to its survival.
None (see section 4.1 above).
4.4 Give an overview of how threats are being abated/could be abated and other recovery actions underway/proposed. Identify who is undertaking these activities and how successful the activities have been to date.
Not applicable (see section 4.1 above). However, continued monitoring of the established sites on the Paroo and Bulloo floodplains (and other populations opportunistically) will shed further light on the dynamics of this mysterious species which remained unrecorded for almost half a century.
4.5 Identify key management documentation for the species e.g. recovery plans, conservation plans, threat abatement plans etc.
Currawinya National Park management plan.
4.6 Are there any management or research recommendations from the documents mentioned in 4.5 or otherwise, that will assist in the conservation of the species?
No.

Section 5. Compilers, referees and references

5.1 Compiler(s) details	
Name(s)	Jenny Silcock
Organisation(s)	University of Queensland
Contact details	
Postal address	133 King Street, Charleville, 4470
Email	jennifer.silcock@uqconnect.edu.au
Phone	(07) 46542389
Date	7 January 2014
5.2 Has this document been refereed? If so, indicate by whom	
5.3 Reference List	

Australian Virtual Herbarium records online, accessed 5 October 2013.

Department of the Environment and Water Resources (2007). *Sclerolaena walkeri* in Species Profile and Threats Database, Department of the Environment and Water Resources, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed 2007-04-17@08:48:50.

Silcock, J.L., Fensham, R.J. & Martin, T.G. (2011). Assessing rarity and threat in an arid-zone flora. *Australian Journal of Botany* **59**: 336–350.

Wilson, P.G. 1984, 'Chenopodiaceae', in *Flora of Australia, Volume 4: Phytolaccaceae to Chenopodiaceae*, Australian Government Publishing Service, Canberra.

Section 6. Declaration

I declare that the information in this nomination and its attachments is true and correct to the best of my knowledge.

Signed:

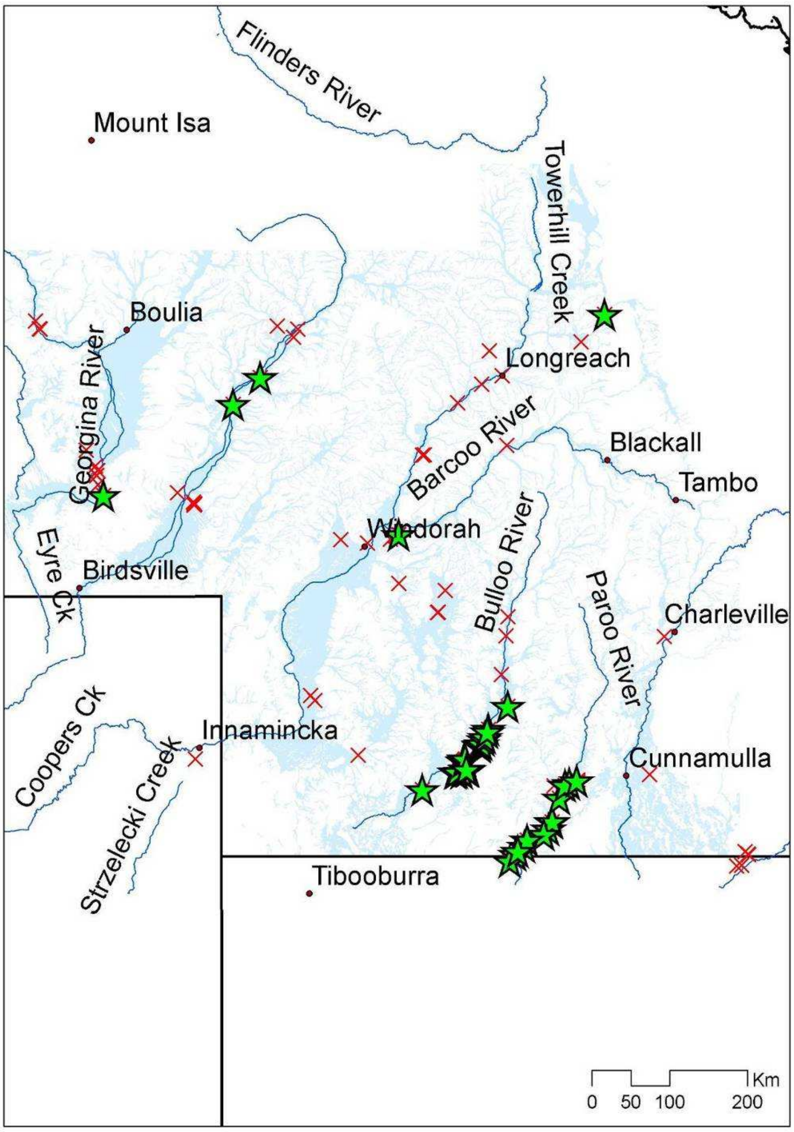
Date:

Section 7. Lodgement instructions
Completed nominations should be electronically lodged at:
Derm_species_tc@derm.qld.gov.au
The original, signed hard copy of the nomination must be posted to:
Species Technical Committee
C/- The Director
Biodiversity and Ecosystem Sciences
Queensland Herbarium
Department of Environment and Resource Management
Brisbane Botanic Gardens,
Mt. Coot-tha Rd,
TOOWONG, Qld 4066


Growth habit and fruiting bodies of *Sclerolaena walkeri*, Paroo River floodplain, July 2007



S. walkeri abundant in disturbed habitats, including (a) Thargomindah motorcycle jump, (b) graded road verge near Thargomindah, and (c) old stock route track, Currawinya NP



Distribution of *Sclerolaena walkeri*, showing main rivers, towns and alluvial habitat (shaded light blue). Green stars show records between 2006 and 2010, red stars show survey sites where the species was not found during this period.

Threatening Processes[1] for *Sclerolaena walkeri*

Threatening Process	Risk Level[2] (not applicable, unknown, none, low, medium, high, extreme)	Ability to Ameliorate[3] (not applicable, unknown, none, low, medium, high, excellent)
Land clearing (historical pre VMA)	Low	not applicable
Land clearing (current post VMA), includes urbanization	Low	High
Current land management practises (e.g. fire regimes, physical disturbance)	Low	Medium
Invasive plants	Low	Not applicable
Impacts of feral/introduced animals (eg grazing)	Low	Medium
Impacts of native animals (vertebrates or invertebrates)	Low	Medium
Accidental destruction (e.g. roadworks, recreation)	Low	High
Small populations (e.g. demographic, genetic effects)	Low	Low
Climate variation (e.g. drought, flood, climate change)	Low	None
Pathogen induced dieback (e.g. *Phytophthora* fungal rootrot; Citrus canker)	Unknown	None
Deliberate harvesting (commercial, cultural, hobbyist)	not applicable	Not applicable
Alteration of hydroecology (e.g. salinity, water table)	Low	None
Mining activities (including quarries)	Low	High

Footnotes

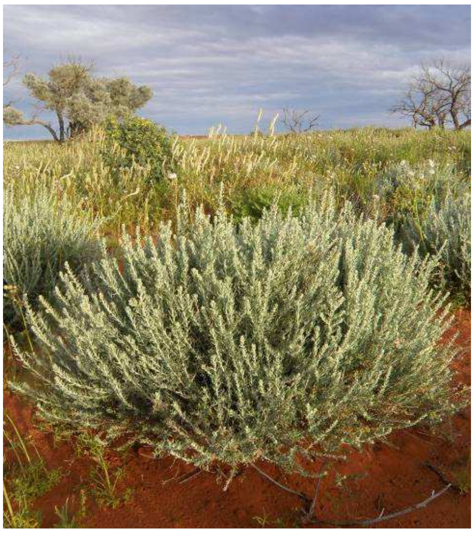
[1] based in part on those proposed by Coates & Atkins (2001).

[2] definitions for Risk Level
not applicable: doesn't apply to this species
unknown: we have no idea based on current data/knowledge
none: there is good data/knowledge on the species and this threatening process does not apply
low: the threatening process is likely to impact on less than 10% of populations and genetic variation
medium: the threatening process is likely to impact on between 10 and 50% of populations and genetic variation
high: the threatening process is likely to impact on between 50 and 90% of populations and genetic variation
extreme: the threatening process is likely to impact on 100% of populations and genetic variation leading to *in situ* extinction

[3] definitions for Ability to Ameliorate, i.e. through human intervention *viz.* government policies, land tenure security, community participation
not applicable: doesn't apply to this species
unknown: we have no idea based on current data/knowledge
none: we can't do anything that will enable conservation of the species *in situ*
low: it is possible to conserve *in situ* less than 10% of populations and genetic variation
medium: it is possible to conserve *in situ* between 10 and 50% of populations and genetic variation
high: it is possible to conserve *in situ* between 50 and 90% of populations and genetic variation
excellent: it is possible to conserve *in situ* 100% of populations and genetic variation

<u>Appendix 6-4.</u> Example of species profile. These were compiled for all candidate species and are available on the Queensland Herbarium server.

Maireana lanosa **(Lindl.) Paul G. Wilson (woolly bluebush) [CHENOPODIACEAE]**



Maireana lanosa on low dune north-west of Ethabuka homestead, north-eastern Simpson Desert

<u>Description</u>
Growth habit: woolly silvery-blue shrub/sub-shrub 50-80cm high x up to 1m across
Leaves: elliptic to narrow-obovate, to 20 mm long, hairy
Flowers: solitary, bisexual
Fruiting body: sparsely hairy; horizontal wing 7–12 mm diam., with a radial slit; 6 erect appendages alternating with perianth lobes, linear, 3–4 mm long.

<u>Distribution</u>
Widespread but patchy across inland and western Australia, encompassing south-western Queensland, western NSW, South Australia, southern NT and the central western coastal area of WA (with scattered historical records around Kalgoorlie). The species has not been

collected in the past 100 years in NSW and is presumed extinct; there are no recent records in South Australia and across large parts of WA. Using only specimens collected in the past 10 years (= 3 on WA coast, 3 in NT and 5 in QLD), extent of occurrence is 873 400 km^2.

Habitat

Variable across its range, mostly on sandy soils including swales, sandplains, sand around ephemeral lakes. Also collected from saline flats and floodplains in WA, the Darling floodplain in NSW and the base of a rocky hill in NT.

In Queensland, the largest recorded population is found on low, rolling dunefields north of Boulia. It grows on the crests and gentle slopes of open, grassy (*Aristida holathera*) red dunes with sparse *Acacia ligulata, A. ramulosa, Hakea leucoptera* ± *Grevillea striata* and scattered *Triodia basedowii* hummocks; diverse scattered shrubs including *Ptilotus obovatus, Eremophla obovata, Sclerolaena diacantha, Melhania oblongifolia, Scaevola parvibarbata, Rhagodia spinescens, Crotalaria eremaea, Isotropsis wheeleri*.

It is scattered on low, undulating dunes and swales supporting low, open *Acacia georginae* along the upper Mulligan River, and sometimes occurs on limestone hills overlain with sand with *Acacia stowardii*. There is a small isolated population on the lower slope of a dune near the Diamantina River, where it is growing with *Triodia basedowii, Aristida holathera, Acacia ligulata, Acacia murrayana, Crotalaria cunninghamii* and a variety of forbs.

Abundance and population estimate

There are only 11 populations known to be extant across its range (i.e. collected in past 10 years). However, surveys in Queensland show that the species remains locally abundant and is not declining in some areas. A population estimate across its range is impossible without targeted surveys.

In Queensland, five populations were found in 2010 and 2011. At the largest population north of Boulia, the species was patchily abundant to scattered for about 10 km of dunefields; mapping of suitable habitat and average population densities suggest at least 250 000 plants in this population. On the eastern edge of the Simpson Desert, it was scattered through gidgee woodland on Cravens Peak for about 2km, mostly under trees (estimated 1000 plants), and a patch of 200 plants was found over a 500m band on a low sandy rise on Ethabuka to the south. No more populations were found in >200 km walked through dunefields and gidgee in this area. Similarly, five plants were found on a dune on Monkira, but a further seven dunes have been searched in this area and no further populations found. However, even with all this search effort, only 20 km^2 (a tiny fraction of the 500 km^2 of dunefields within the species range) was searched, and total population size in Queensland is probably much larger than these figures indicate.

Demography and threats

Collection record certainly indicates a declining trend across its range. It is apparently highly palatable, and two of the five records in the Northern Territory note that most plants were browsed (one by cattle at Yuendemu, the other by camels at Haasts Bluff) (Dave Albrecht, pers.comm.). However, the species had not been collected in Queensland in the past 20 years (and not in the Mulligan River area since Vogan in 1889!), and it was found in abundance at one site and quite commonly at a further two. It was ungrazed at all sites surveyed, and there were small, slender plants to <30cm tall and a range of size classes at the Boulia population, indicating healthy levels of recruitment under current management. Thus some apparent rarity and decline may be due to low collecting effort.

Conservation status

Listed as Presumed Extinct in NSW, Near Threatened in NT. Not listed under EPBC or in Queensland. Does not warrant listing in Queensland based on survey results, however targeted surveys in other states (at sites of historical collections in NSW, SA, WA and NT) are necessary to assess national conservation status.

Notes

M. lanosa is close to *M.lobiflora*, but differs from that species in having the leaves of the fruiting branches noticeably smaller than those on the lower parts, and the erect projections above the wing of the fruits are always linear in *M. lanosa*, never club-shaped. *M. lobiflora* is a low-growing, sprawling perennial forb. One record from Queensland (Purdie 1979, Springvale) is from habitat more typical of *M. lobiflora* and is a small forb to 10cm high – this specimen should be checked and re-detted if necessary.

References

Cunningham G.M, Mulham WE, Milthorpe PL, Leigh JH (1992) 'Plants of western New South Wales', Inkata Press, Melbourne

Plant NET (New South Wales Flora Online) Maireana lanosa species profile, available at http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Maireana~lanosa [accessed 25 September 2013].

Wilson, Paul G. (1975) A Taxonomic Revision of the genus *Maireana* (Chenopodiaceae). Nuytsia 2(1): 20.

Wilson, P.G. 1984, 'Chenopodiaceae', in Flora of Australia, Volume 4: Phytolaccaceae to Chenopodiaceae, Australian Government Publishing Service, Canberra.

<u>Appendix 7-1.</u> Rare and threatened fauna species, inland eastern Australia. Status is based on Woinarski et al. (2014) for mammals, Garnett et al. (2011) for birds and EPBC listings for reptiles and fish. Individual state listings vary and some the Least Concern species in the latest national treatments (Woinarski et al. 2014 and Garnett et al. 2011) remain listed in one or more states in inland eastern Australia, and are included in the table. References as per table with additional input from species recovery plans for each State and Territory, where available online. CE, Critically Endangered; E, Endangered; V, Vulnerable; NT, Near Threatened. Bioregion abbreviations: MUL, Mulga Lands; CHC, Channel Country; MGD, Mitchell Grass Downs; NWH, North West Highlands; BB, Brigalow Belt. For threats, X = not documented for the species in the study area; Severe = strong correlative evidence as being major cause of decline in study area; Moderate = documented as a contributing factor in decline; Suspected = no correlative evidence but thought to be a factor and mentioned in recovery plans or literature; Possible = no firm evidence but mentioned in literature.

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
BIRDS														
Amytornis barbatus barbatus (Grey grasswren - Bulloo)	E	Floodplain and wetlands of Bulloo River on QLD-NSW border	No evidence of change	Lignum and swamp canegrass	No evidence of decline	Possible	Possible	X	Suspected (cattle)	Suspected (rabbits, pigs)	X	X	Very naturally restricted; cattle grazing considered main threat especially in dry years	Garnett et al. (2011)
Amytornis dorotheae (Carpentarian grasswren)	NT	North-west QLD and adjacent NT	Four separate occurrences - may once have been a single population	Long-unburnt spinifex, mostly in rocky areas	Continuing decline over past three decades in NT	X	X	X	X	X	Severe	Suspected		Garnett et al. (2011); Perry et al. (2011)
Amytornis modestus obscurior (Thick-billed grasswren - north-western NSW)	CE	Far north-western NSW - historical collections from Milparinka and Tibooburra	A population rediscovered in 2008 near Packsaddle	Low gibber ridge with scattered trees, shrubs and Chenopods	Uncertain; population very smalll but no documented decline	X	Possible	X	Suspected (sheep, cattle)	Suspected (goats, rabbits)	X	X	Overgrazing considered main potential threat	Garnett et al. (2011)
Amytornis striatus striatus (Striated grasswren - sandplain)	NT	Scattered across arid Australia, including far western QLD and central NSW	No evidence of change	Sandplains domainted by mature spinifex ± mallees	Uncertain; possibly declining	Possible	Possible	X	Possible	Possible	Suspected	X	More extensive and frequent fires considered major threat; other threats speculative	Garnett et al. (2011)
Elanus scriptus (Letter-winged kite)	NT	Fluctuating range in eastern arid zone, occasionally irrupting across continent; core habitat in CHC	No evidence of change	Open herblands and sparse grassland	Irruptive dynamics linked to long-haired rat populations but no evidence of decline	X	X	X	X	X	X	X	Competition for prey + impacts of cats on nestlings unquantified; population may approach 1000 in dry years	Garnett et al. (2011); Peter McRae, pers.comm.
Epthianura crocea crocea (Inland yellow chat)	LC	Patchy across northern and eastern inland Australia, including LEB	No evidence of change	Low vegetation around margins of wetlands (natural and artificial)	Unknown; no decline documented	X	X	Outside study area	Suspected	Suspected	Possible	Suspected	Closure of bores, feral animals, weeds, and overgrazing all potential threats, but no decline documented	Garnett et al. (2011); Max Tischler, pers.comm.
Erythura gouldiae (Gouldian finch)	NT	Northern Australia, from Kimberley to north QLD; occasional to central-west QLD	Similar, but contractions and declines within this range	Tropical savannah woodlands	Has declined well below historical levels but declines appear to have ceased	X	X	X	Moderate	X	Severe	X	Regular extensive fires are regarded as major threat in northern Australia + heavy cattle grazing can reduce seed availability	Garnett et al. (2011); Woinarski & Legge (2013)
Falco hypoleucos (Grey falcon)	V	Widespread in arid and semi-arid Australia; always low densities	May have declined in parts of semi-arid NSW	Variable, but centred on inland drainage lines	No evidence of decline in study area	X	X	Suspected	Suspected	X	X	X	All threats speculative and concentrated on wetter margins of range, especially in semi-arid NSW	Garnett et al. (2011); Max Tischler, pers.comm.

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Grantiella picta (Painted honeyeater)	V	Sparse from south-eastern Australia to north-west QLD and east NT; major concentrations south of 26°on inland slopes of Great Dividing Range	No evidence of major contraction of range	Moves seasonally into semi-arid areas after breeding; mostly in Acacia-dominated woodlands	Apparently declining, particularly in south of range; no evidence of decline in study area	X	X	Outside study area	Suspected	Suspected	X	X	Extensive clearing particularly of brigalow to east of study region major threat + overgrazing thought to limit tree regeneration in more heavily grazed areas	Garnett et al. (2011)
Lophochroa leadbeateri leadbeateri (Major Mitchell cockatoo - eastern)	NT	South-west QLD (ML and eastern CHC), through western NSW into adjacent eastern SA and north-west Vic	No evidence of change, except apparent expansion east to St George c.1930s	Semi-arid and arid woodland dominated by mulga, cypress, poplar box, belah or mallee	No evidence of decline in study area	X	X	Suspected	Suspected	Suspected	X	X	Lack of regeneration of Callitris through domestic and feral grazing a threat in Vic, but pine regenerating well in QLD and NSW	Garnett et al. (2011)
Lophoictinia isura (Square-tailed kite)	LC	Widespread across Australia; scattered through inland areas	No evidence of change	Variety of habitats; preference for timbered watercourses	No evidence of decline	X	X	Suspected	X	X	X	X	No decline or threats documented but remains listed in QLD and NSW	Garnett et al. (2011)
Malurus coronatus macgillivray (Purple-crowned fair-wren - eastern)	NT	Along most rivers draining into Gulf from Leichhardt River in QLD to Roper River in NT	No evidence of change	Riparian zone with Melaleuca and Eucalyptus spp. + Pandanus, shrubs or dense Chionachne cyathopoda	Decline inferred due to perceived decline in habitat quality, but only documented decline was on Leichhardt River following damming	Possible	X	X	Suspected	Suspected	Suspected	Suspected	Mining disturbance also considered a threat	Garnett et al. (2011)
Ninox connivens connivens (Barking owl - southern)	NT	Temperate and arid regions, inland to Lake Eyre, Bulloo and Murray Darling Basin systems	No evidence of change	Restricted to drainage lines/riparian areas in study area	No evidence of decline in study area	Possible	Possible	Outside study area	X	X	X	X	Secondary poisoning through baiting a potential threat; other threats mostly operate in wetter areas outside study area, primarily extensive landclearing	Garnett et al. (2011)
Oxyura australis (Blue-billed duck)	NT	South-east Australia and south-west WA with scattered inland records	No evidence of change	Appear to rest on inland wetlands after good rain, moving to more permanent waters during dry times	No evidence of decline in study area, but overall inferred to be declining	X	X	Outside study area	Suspected	Suspected	Suspected	Suspected (introduced fish)	Loss of habitat through water diversion, drainage of swamps and reduced flows major threat	Garnett et al. (2011)
Pezoporus occidentalis (Night parrot)	E	Historically recorded throughout arid and semi-arid Australia; most records before 1880s	Few widely-accepted records since 1935	Variable, but mostly hummock grasslands	Uncertain; population estimates very low confidence; few records since 1935 suggest decline	Suspected	Suspected	X	Suspected	Suspected	Suspected	X	No evidence linking any threatening process to apparent declines; all estimates of population parameters essentially guesswork	Garnett et al. (2011)
Psedononmus torquatus (Plains wanderer)	E	Formerly more widespread in eastern Australia	Northern Victoria and south-central NSW (Riverina) + south-western QLD	Sparse grassland	Population in QLD estimated at 1000 birds; no decline documented in QLD	Suspected	X	Outside study area	X	X	X	X	Main threat in Riverina is cultivation of native grassland; other threats (very high grazing pressure and fox predation) also not issues in QLD part of range. Cat predation is suspected.	NSW NPWS (2002); Garnett et al. (2011)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Rostratula australis (Australian painted snipe)	E	Eastern, northern and south-western Australia	No evidence of change	Shallow, vegetated temporary wetlands	Apparent decline difficult to quantify due to different survey methods, cryptic and dispersive habit and lack of surveys	X	X	Outside study area	Suspected	Suspected	X	X	Loss and degradation of wetlands through drainge and diversions, especially in MDB, major threat; also grazing and trampling in some regions	Garnett et al. (2011)
FISH														
Chlamydogobius micropterus (Elizabeth springs goby)	CE (IUCN); E (EPBC)	Unknown; many springs are extinct in the Springvale supergroup so possible it was more widespread	Restricted to Elizabeth Springs on Springvale station east of Boulia, found in 5-14 springs	GAB discharge springs; preference for larger springs	May have declined historically due to spring extinctions and diminished flow at Elizabeth Springs; populations now appear stable	X	X	Severe	Moderate	Moderate	X	X	Gambusia not present at Springvale	Adam Kerezsy, pers.comm.; Fensham et al. (2010)
Chlamydogobius squamigenus (Edgbaston goby)	CE (IUCN); E (EPBC)	Unknown; many springs are extinct in the Barcaldine supergroup so possible it was more widespread	Restricted to Edgbaston GAB springs + bore drains on Crossmoor north of Longreach; has been found in 19 springs	GAB discharge springs	May have declined historically due to spring extinctions; populations now appear stable	X	X	Severe	Moderate	Moderate	X	Moderate		Adam Kerezsy, pers.comm.; Fensham et al. (2010)
Maccullochella peelii peelii (Murray cod)	CE (IUCN); E (EPBC)	Rivers of MDB from QLD to VIC; in Warrego and Balonne catchments in study area	No evidence of severe contration, but now more patchily distributed	Lower to mid-reaches of rivers	No evidence of decline in study area	X	X	Outside study area	X	X	X	X	Main threats are changes to flow regimes and declines in water quality; probably stable in study area due to absence of these threats	Curtis et al. (2012)
Scaturiginichthys vermeilipinnis (Red-finned blue-eye)	CE (IUCN)	Unknown; many springs are extinct in the Barcaldine supergroup so possible it was more widespread; when discovered known from eight springs	Survives in two springs at Edgbaston + numerous translocated populations	GAB discharge springs	Declining	X	X	Severe	Moderate	Moderate	X	Severe		Kerezsy & Fensham (2013)
MAMMALS														
Antechinomys laniger (Kultarr)	LC	Widespread but patchy across inland Australia including study area	No evidence of change	Open country including stony and sandy plains with sparse shrubs and grasses	Fluctuating abundance, but no evidence of ongoing decline	Possible	Possible	X	X	X	X	X	Abundant in MUL in 2012	Stephen Peck & Peter Brice, pers.comm.; Woinarski et al. (2014)
Bettongia lesueur (Burrowing bettong/ boodie)	V	Across arid and semi-arid Australia; locally abundant in good seasons	Extinct in study area and on mainland in wild	Variable, in study area warrens are often found on small silcrete rises	Extinct in study area	Severe	Severe	X	X	X	Possible	X	Extensive warren systems and role as ecosystem engineer	Dickman et al. (1993); Noble et al. (2007); Woinarski et al. (2014)
Bettongia penicillata (Brush-tailed bettong/woylie)	CE	Most of arid and semi-arid Australia south of Tropic of Capricorn, abundant in many areas	Extinct on mainland except for fenced areas	Sand plains and dunes with spinifex	Extinct in study area	Severe	Severe	X	X	X	Possible	X		Burbidge et al. (1988); Dickman et al. (1993); Lunney (2001); Woinarski et al. (2014)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Caloprymnus campestris (Desert rat-kangaroo)	Extinct	South-west QLD and north-east SA; sometimes locally common	Extinct	Distinct preference for ecotonal areas between gibber plains and loamy flats	Extinct	Severe	Severe	X	Suspected	Suspected (rabbits)	X	X		Finlayson (1932); Burbidge et al. (1988); Dickman et al. (1993); Woinarski et al. (2014)
Chaeropus ecaudatus (Pig-footed bandicoot)	Extinct	Western study area and across arid and semi-arid NT, WA, SA and Victoria	Extinct	Variable	Extinct	Severe	Severe	X	Suspected (sheep)	Suspected (rabbits)	X	X		Dickman et al. (1993); Lunney (2001); Woinarski et al. (2014)
Chalinolobus picatus (Little pied bat)	LC	Throughout NSW and eastern QLD	No evidence of change	Wide range of forested habitats	Uncertain, but rate of decline less than IUCN threshold	Possible	Possible	Suspected	Possible	Possible	X	X		Woinarski et al. (2014)
Conilurus albipes (White-footed rabbit rat)	Extinct	South-eastern Australia, probably inland to Bulloo River and upper Cooper Creek	Extinct	Mostly recorded from grassy woodlands	Extinct	Severe	Possible	X	Suspected	Suspected	X	X	Possible but unknown role of disease in decline	Woinarski et al. (2014)
Dasycercus blythi (Brush-tailed mulgara)	LC	Widespread across western inland Australia, east to Simpson Strzelecki dunefields	No evidence of change	Spinifex grassland + adjacent vegetation types	Thought to have declined historically but recent evidence suggests more secure than previously thought	Severe	Severe	X	Suspected	Suspected	Unknown	X	Fluctuates seasonally; appears tolerant of a wide range of fire regimes	Kortner et al. (2007); Pavey et al. (2011); Woinarski et al. (2014)
Dasycercus cristicauda (Crest-tailed mulgara)	NT	Widespread across inland Australia	Widespread across inland Australia	Sparsely vegeated dunes, herblands, sparse grassland, gibber plains	Variable and uncertain; historical decline assumed but increasing in some areas with recent good seasons	Moderate	Moderate	X	Suspected	Severe (rabbits)	Unknown	X	Abundance varies substantially with rainfall; correlative responses to decrease in rabbit numbers	Woinarski et al. (2014)
Dasyuroides byrnei (Kowari)	V	CHC of south-west QLD and north-west SA	No evidence of change	Gibber plains	Apparently declining but fluctuates substantially	X	X	X	Severe	X	X	X	Correlative evidence of negative impact of livestock relating to decrease in shelter and prey availability.	Canty (2012); Woinarski et al. (2014)
Dasyurus geoffroii (Chudditch/western quoll)	NT	Relatively abundant over >70% of Australia	Restricted to WA where it is considered 'Conservation Dependent'	Variable	Extinct in study area	Suspected	Severe	X	Possible	Possible	Possible	X	Numerous factors implicated in decline	Finlayson (1935); Woinarski et al. (2014)
Dasyurus hallucatus (Northern quoll)	E	Northern Australia, particularly in more rugged areas; into north-east of study area in MGD	No evidence of change	Rocky areas	Rapid decline	Moderate	Moderate	Moderate	X	X	X	Severe (cane toads)		Woinarski et al. (2014)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Hipposideros stenotis (Northern leaf-nosed bat)	NT	Northern Australia from Kimberley to North West Highlands; series of disjunct populations	No evidence of change	Rugged rocky areas	Uncertain; decline inferred	Possible	X	X	X	X	Possible	X	Little known of threats or population trends but disturbance of roost sites, inappropriate fire regimes and feral cat predation all possible	Milne & Pavey (2011); Woinarski et al. (2014)
Isoodon auratus (Golden bandicoot)	V	Widespread, extening into western QLD and NSW	Restricted to Kimberley and islands of Pilbara and Kimberley coast	Variable; sandstone ranges and riparian grassland within current range	Extinct in study area	Severe	X	X	X	X	X	X		Dickman et al. (1993); Lunney (2001); Woinarski et al. (2014)
Lagorchestes conspicillatus (Spectacled hare-wallaby)	NT	Northern half of continent	Now patchy and uncommon; recent records from north-eastern CHC and NWH	Tropical grasslands, open forest and woodland	Significant past declines which continue in many areas, including in central QLD	Severe	Severe	Outside study area	X	X	X	X		Woinarski et al. (2014)
Lagorchestes leporides (Eastern/brown hare-wallaby)	Extinct	Central NSW, southern Victoria, south-eatern SA, into southern QLD	Extinct	Open habitat on grassy plains	Extinct	Moderate	Severe	X	X	X	X	X	Likely extinction date predated intensive European settlement but coincided with arrival of foxes	Woinarski et al. (2014)
Leporillus apicalis (Lesser stick-nest rat)	Extinct	Across semi-arid and arid WA, SA, Vic, southern NT and western NSW	Extinct	Variety of habitats; extending into more arid areas than L. conditor	Extinct	Severe	Severe	X	Suspected (sheep)	Suspected (rabbits)	X	X	Degradation of key 'refuges' by sheep and rabbits suspected to have interacted with predators	Copley (1999); Woinarski et al. (2014)
Leporillus conditor (Greater stick-nest rat)	NT	Across semi-arid and arid southern Australia, into south-western QLD and north-western NSW	Extinct on mainland	Shrublands	Extinct in study area	Severe	Severe	X	Suspected (sheep)	Suspected (rabbits)	X	X	Degradation of key 'refuges' by sheep and rabbits suspected to have interacted with predators	Copley (1999); Woinarski et al. (2014)
Macroderma gigas (Ghost bat)	V	Widespread but disjunct populations across northern two-thirds of Australia	No evidence of change	Deep caves and disused mines	Continuing decline in QLD	X	X	X	X	X	X	X	Many arid-zone populations have disappeared; total population size estimated <10 000. Threats: disturbance of roosts; mining; collision with fences	Woinarski et al. (2014)
Macrotis lagotis (Greater bilby)	V	Occurred throughout arid and semi-arid Australia	Western deserts extending to coast on Dampier Peninsula; only remaning wild population in eastern Aust in CHC	Stony clay plains with sparse grass and herb cover	Extinct from NSW in 1940s and SA in 1930s; has declined across QLD and decline apparently continues	Severe	Severe (only in southern areas; not present wtihin current range)	X	X	X	X	X	Predation by cats following long-haired rat plagues major threat; scant evidence of direct impacts of cattle; fire very unlikely even after exceptional seasons on CHC plains	Finlayson (1935); McRae (2004); Peter McRae, pers.comm.
Macrotis leucura (Lesser bilby)	Extinct	Central deserts of WA, NT, SA and probably into Simpson Desert in south-western QLD	Extinct	Sandplain and sand dune deserts but also mulga and tussock grassland	Extinct	Severe	Severe	X	X	X	X	X	Predation by foxes and cats catastrophic	Burbidge et al. (1988); Dickman et al. (1993); Finlayson (1935); Woinarski et al. (2014)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Mormopterus eleryi (Bristle-faced/hairy-nosed free-tail bat)	NT	Widespread but apparently sparse across central Australia	No evidence of change	Mostly open woodlands, especially riparian areas	Limited knowledge, but possible continuing decline	X	X	Suspected	X	Suspected (goats)	Suspected	X	No evidence for threats, but broad-scale vegetation clearance in parts of its range in QLD (eastern MUL and BB) suggests declines	Woinarski et al. (2014)
Notomys amplus (Short-tailed hopping mouse)	Extinct	Central and western arid zone, into western edge of study area	Extinct	Sand dunes and sandplains	Extinct	Severe	X	X	Possible	Possible	X	X	Predation by feral cats; rabbits and livestock may have contributed, but both absent from deserts at presumed time of extinction	Woinarski et al. (2014)
Notomys cervinus (Fawn hopping mouse)	NT	Formerly widespread across most of Lake Eyre Basin	CHC of QLD and SA; overall historical decline is >50% of its pre-European distribution	Gibber plains and alluvial flats	Extreme fluctuations but little evidence of ongoing decline; SA populations seem stable	Moderate	Moderate	X	Suspected	Suspected	X	X	Trampling by livestock potentially a threat	Brandle et al. (2008); Woinarski et al. (2014)
Notomys fuscus (Dusky hopping mouse)	V	Widespread in arid Australia	Arid SA, south-west QLD, north-west NSW; no records in NT since 1939	Dunefields with perennial species, but apparently not in spinifex	Irruptive population dynamics; no evidence of decline in study area	Severe	Severe	X	X	Suspected (rabbits)	X	X	Surveys in 2011-12 after good rainfall considerably extended its range	Moseby et al. (1999); Woinarski et al. (2014)
Notomys longicaudatus (Long-tailed hopping mouse)	Extinct	Arid and semi-arid WA, SA, southern NT and far western NSW	Extinct	Probably similar to fawn hopping mouse	Extinct	Severe	Severe	X	X	X	X	X	Pastoral impacts largely absent from much of its range at time of extinction	Woinarski et al. (2014)
Nyctophilus corbeni (South-eastern long-eared bat)	V	Inland south-eastern Australia, from central QLD to far eastern SA	No evidence of change	Woodlands and mallee communities	Little information, but inferred decline due to habitat loss	Possible	Possible	Outside study area	Possible	Possible	Suspected	X	Habtiat loss through clearing considered major threat	Woinarski et al. (2014)
Onycholgalea fraenata (Bridled nailtail wallaby)	V	Across inland eastern Australia, from north-central Victoria to north QLD; once common	Single remnant population to east of study area (Taunton NP) + three translocated populations	Historically known from wide range of vegetation types	Rapid decline following European settlement - no records from 1937 until its rediscovery in 1973; translocated population in study area stable	Severe	Severe (not present at Taunton)	Outside study area	Suspected (sheep)	X	Possible	Severe (buffel grass)	Invasion of buffel grass serious issue; grazing considered major cause of historic decline + hunting and dingo predation.	Woinarski et al. (2014)
Onycholgalea lunata (Crescent nailtail wallaby)	Extinct	Widespread in semi-arid WA and western deserts, south-western NSW and south-eastern Australia	Extinct	Variable, including stony hills; especially abundant in mulga country	Extinct	Severe	Severe	X	Possible	X	Possible	X	Drastic decline of mammals in Flinders Ranges after sheep overgrazing following drought; no evidence of grazing impacts on this species in study area	Woinarski et al. (2014)
Perameles bougainville (Western barred bandicoot)	V	Widespread in southern Australia, including western NSW	Now restricted to islands and captive populations	Poorly known and apparently variable	Extinct in study area	Possible	Severe	X	X	Suspected (rabbits)	X	X	Predation by foxes proved catastrophic; also cats and rabbits (competition) may have played a role	Dickman et al. (1993); Lunney (2001); Woinarski et al. (2014)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Perameles eremiana (Desert bandicoot)	Extinct	Widespread in arid Australia, just into far west of study area in NT and north-east SA	Extinct	Stony and sandy deserts with hummock and tussock grasses	Extinct	Severe	Severe	X	X	X	Possible	X	Predation by foxes and cats catastrophic, potentially compounded by large wildfires	Dickman et al. (1993); Lunney (2001); Woinarski et al. (2014)
Petrogale purpureicollis (Purple-necked rock wallaby)	NT	North-west QLD, extending south to Toomba/Toko Ranges on northern edge of Simpson Desert (Hodgkinson 1878)	North-west QLD, from Lawn Hill to near NT border; series of discontinuous colonies	Rocky ranges	Some historic decline including loss of some subpopulations; now apparently stable in study area	X	X	X	X	Severe (goats)	Possible	Possible (buffel)	Habitat degradation and resource depletion due to goats considered most severe threat; also extensive wildfires, buffel invasion and mining.	Woinarski et al. (2014)
Petrogale xanthopus subsp. celeris (Yellow-footed rock wallaby)	V	South-western QLD, concentrated on Grey Range	Disjunct populations from Eromanga to Blackall in Grey Range system	Rocky ranges; strong preference for gorges and boulder fields	Recent surveys have shown species to be abundant at many sites and no declines documented since 1980s surveys	X	Suspected	Suspected	X	Moderate (goats)	X	X	Clearing in valleys between ranges thought to be a threat, limiting movement between sub-populations	Goron et al. (1978); Peter McRae, pers.comm.
Petrogale xanthopus subsp. xanthopus	NT	North-western NSW and inland South Australia	Disjunct localities in ranges in north-western NSW and SA	Rocky ranges	Historic decline documented	Severe	X	X	X	Severe (goats)	X	X		Woinarski et al. (2014)
Phascolarctos cinereus (Koala)	V (south-east QLD)	Across mainland eastern Australia	Scattered in eastern and northern MUL in QLD in study area	Riparian woodlands; occasionally recorded in gorges in northern MUL	MUL population has declined by 80% over recent decades	X	X	Severe	X	X	X	X	Combined impacts of habitat fragmentation + increased temperatures, likely to become more severe with climate change	Seabrook et al. (2011); Davies et al. (2014)
Pseudantechinus mimulus (Carpentarian antechinus)	NT	North-western Australia and northern NT	Recent records from NT and north-west QLD infer greater range than previously recognised	Ranges, mostly sandstone but also occurs on limestone	Weak evidence of an ongoing decline	Possible	X	X	X	X	Possible	Possible (buffel)	Threats poorly understood but could include inappropriate fire regimes, feral cat predation and buffel grass invasion	Woinarski et al. (2014)
Pseudomys australis (Plains mouse/plains rat)	V	Widespread; historical records from south-west QLD, Nullarbor, western Vic, Darling Downs and northern NSW	South-east NT/ central SA; not recorded in NSW or QLD since 1936 until 2001 discovery of remains in owl pellet, Diamantina NP	Gibber plains on cracking clay especially around run-on areas (but formerly occurred in a wider range of habitats)	Substantial contraction in range, but current trends difficult to discern because of extreme fluctuations	Severe	Severe	X	Suspected	Suspected	X	X	Trampling of burrows and destroying cover may have an effect, but strong evidence for predation from both foxes and cats	Moseby & Kemper (2008); Woinarski et al. (2014)
Pseudomys fieldi (Djoongan/ Shark Bay mouse)	V	Across WA, SA, southern NT and into north-west NSW	Extinct on mainland	Outwash fans of ranges in Central Australia	Extinct	Severe	Severe	X	Possible	Possible	X	X		Woinarski et al. (2014)
Pseudomys gouldii (Gould's mouse)	Extinct	Throughout much of SA and western and northern NSW	Extinct	Poorly known, but thought to include sandhills and plains	Extinct	Suspected	X	X	Possible	Possible	X	X	Causes of decline poorly understood	Woinarski et al. (2014)
Rhinonicteris aurantia (Orange leaf-nosed bat)	LC	Across northern Australia from Pilbara to Mt Isa area	Across northern Australia from Pilbara to Mt Isa area	Rocky caves and escarpments; roosting in caves or abandoned mine adits	May be some decline associated with threats to nest sites, but not enough to warrant listing	X	X	X	X	X	Possible	X	Human disturbance of roost sites a threat	Woinarski et al. (2014)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Sminthopsis douglasi (Julia Creek dunnart)	NT	Endemic to north-western QLD, in MGD and Desert Uplands bioregions	Endemic to north-west QLD, in MGD and DU bioregions	MGD	Uncertain	Severe	Moderate	X	X	X	Suspected	Suspected (prickly acacia)	Limited knowledge of population size and trends; numbers fluctuate with seasonal conditions + low detectability.	Woinarski et al. (2014); Lundie-Jenkins & Payne (2000)
Trichosurus vulpecula (Brush-tailed possum)	LC	Once common and widespread in arid zone	Common in wetter areas, extending to about Kyabra Creek in western QLD	Riparian woodlands and rocky ranges	Has declined in the arid zone; current trends in study area unknown	Moderate	Moderate	X	Suspected	Suspected	X	X	Interacting factors implicated in delinces, involving drought, habitat changes and predators	Kerle et al. (1992); Dickman et al. (1993)
REPTILES														
Acanthophis antarcticus (Common death adder)	LC	Several disjunct populations through southern and eastern Australia, but sparse	No evidence of change	Wide variety of habitats in association with dense leaf litter	Uncertain	X	X	Suspected	Suspected	Suspected	X	Possible (cane toad)	Grazing pressure may reduce prey; land clearing and cultivation has fragmented habitat in some areas	Wilson & Swan (2010)
Aspidites ramsayi (Woma)	E (IUCN)	Subhumid and arid areas throughout interior of Australia; in eastern MUL in study area	No evidence of change	Wide variety of habitats	Uncertain	Suspected	Suspected	Suspected	X	X	X	X	Cats and foxes may prey on young snakes; also considerable direct persecution	Wilson & Swan (2010)
Ctenotus agrestis	LC	Central-western QLD, between Aramac and Boulia	No evidence of change	Mitchell grasslands on cracking clay	Uncertain	X	X	X	X	X	X	X	Naturally restricted; no good estimates of population size or trends	Alicia Whittington, pers.comm.; Wilson & Swan (2010)
Ctenotus astarte	LC	South-west QLD, from Betoota north to Boulia area	No evidence of change	Arid shrublands on stony and clay soils	Uncertain	X	X	X	X	X	X	X	Naturally restricted; no good estimates of population size or trends	Wilson & Swan (2010)
Ctenotus schevilli (Black-soil rises skink)	LC	MGD from Richmond to Muttaburra and Aramac	No evidence of change	Mitchell grasslands on cracking clay	Uncertain	X	X	X	X	X	X	X	Naturally restricted; no good estimates of population size or trends. Found in abundance during surveys on Lochern NP in 2012	Alicia Whittington, pers.comm.; Wilson & Swan (2010)
Ctenotus septenarius	LC	Southern NT and south-western QLD, in a narrow band	No evidence of change	Sparsely vegetated stony hills and gullies	Uncertain	X	X	X	X	X	X	X	Naturally restricted; no good estimates of population size or trends	Wilson & Swan (2010)
Ctenotus serotinus	LC	Restricted to Diamantina Lakes area in south-western QLD	No evidence of change	Dunes and adjacent stony soils	Uncertain	X	X	X	X	X	X	X	Naturally restricted; no good estimates of population size or trends	Alicia Whittington, pers.comm.; Wilson & Swan (2010)
Egernia rugosa (Yakka skink)	V (EPBC)	Disjunct populations in subhumid and semi-arid QLD; into eastern MUL in study area	No evidence of change	Mulga woodlands	No declines documented in the MUL + surveys have found many additional populations	X	X	Suspected	Suspected	X	X	X		Stephen Peck, pers.comm.
Furina barnardi (Yellow-naped snake)	LC	Central and eastern QLD, inland to about Windorah	No evidence of change	Variable	Uncertain	X	X	X	X	X	X	X	Few records and very poorly known	Alicia Whittington, pers.comm.; Wilson & Swan (2010)

Species	Status	Distribution at European settlement	Current distribution	Broad habitat preferences	Population trend	Cats	Foxes	Habitat loss/ fragment-ation	Livestock impacts	Feral herbivore impacts	Inappropriate fire regimes	Other introduced species	Notes	References/ pers.comm.
Oxyuranus microlepidotus (Inland taipan)	LC	Far south-west QLD and north-east SA + old records from NSW	No recent NSW records; no evidence of contractions in QLD or SA	Sparsely vegetated cracking clay plains	Fluctuating abundance in response to long-haired rat plagues	X	X	X	X	X	X	X	No evidence of decline or documented threats	Wilson & Swan (2010); Stephen Peck & Peter McRae, pers.comm.
Pseudechis colletti (Collett's snake)	LC	MGD in central-western QLD	No evidence of change	Mitchell grasslands	Largely unknown; may be declining	X	X	X	X	X	X	X	Active at night after rain, a time when sampling is difficult - may account for sparse records.	Stephen Peck, pers.comm.; Wilson & Swan (2010)
Pseudonaja guttata (Speckled brown snake)	LC	South-western QLD and eastern NT	No evidence of change	Grasslands on cracking clay plains	Uncertain	X	X	X	X	X	X	X	Probably just sparsely collected	Wilson & Swan (2010)

References

Brandle R., Moseby K. E. & Adams M. (1999) The distribution, habitat requirements and conservation status of the plains rat, Pseudomys australis (Rodentia : Muridae). *Wildlife Research* 26, 463-77.

Burbidge A. A., Johnson K. A., Fuller P. J. & Southgate R. I. (1988) Aboriginal knowledge of the mammals of the central deserts of Australia, Aust. *Wild. Res.* 15, 9-39.

Canty P. (2012) Kowari, Dasyuroides byrnei. In: *Queensland's Threatened Animals* (eds L. K. Curtis, A. J. Dennis, K. R. McDonald, P. M. Kyne and S. J. S. Debus) pp. 338-9. CSIRO Publishing, Collingwood.

Copley P. (1999) Natural histories of Australia's stick-nest rats, genus Leporillus (Rodentia : Muridae). *Wildlife Research* 26, 513-39.

Curtis L. K., Dennis A. J., McDonald K. R., Kyne P. M. & Debus S. J. S. (2012) *Queensland's Threatened Animals*. CSIRO Publishing, Collingwood.

Davies N., Gramotnev G., Seabrook L., McAlpine C., Baxter G., Lunney D. & Bradley A. (2014) Climate-driven changes in diet composition and physiological stress in an arboreal folivore at the semi-arid edge of its distribution. *Biological Conservation* 172, 80-8.

Dickman C. R., Pressey R. L., Lim L. & Parnaby H. E. (1993) Mammals of particular conservation concern in the western division of New South Wales. *Biological Conservation* 65, 219-48.

Fensham R. J., Ponder W. F. & Fairfax R. J. (2010) Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin. Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Department of Environment and Resource Management, Brisbane.

Finlayson H. H. (1932) Caloprymnus campestris: its recurrence and characters. South Australian Museum, Adelaide.

Finlayson H. H. (1935) *The Red Centre: man and beast in the heart of Australia*. Angus & Robertson, Sydney.

Garnett S. T., Szabo J. K. & Dutson G. (2011) *The Action Plan for Australian Birds 2010*. CSIRO Publishing, Collingwood.

Gordon G., McGreevy D. G. & Lawrie B. C. (1978) The yellow-footed rock wallaby, Petrogale xanthopus Gray (Macropodiae) in Queensland. *Australian Wildlife Research* 5, 295-7.

Kerezsy A. & Fensham R. (2013) Conservation of the endangered red-finned blue-eye, Scaturiginichthys vermeilipinnis, and control of alien eastern gambusia, Gambusia holbrooki, in a spring wetland complex. *Marine and Freshwater Research* 64, 851-63.

Kerle J. A., Foulkes J. N., Kimber R. G. & Papenfus D. (1992) The decline of the brushtail possum, Trichosurus vulpecular (Kerr 1798) in arid Australia. *Rangeland Journal* 14, 107-27.

Kortner G., Pavey C. R. & Geiser F. (2007) Spatial ecology of the mulgara in arid Australia: impact of fire history on home range size and burrow use. *Journal of Zoology* 273, 350-7.

Lundie-Jenkins G. & Payne A. (2000) Recovery Plan for the Julia Creek dunnart (Sminthopsis douglasi) 2000-2004. [Online]. Queensland National Parks & Wildlife Service, Brisbane

Lunney D. (2001) Causes of the extinction of native mammals of the Western Division of New South Wales: an ecological interpretation of the nineteenth century historical record. *The Rangeland Journal* 23, 44-70.

McRae P. D. (2004) Aspects of the Ecology of the Grea ter Bilby, Macrotis lagotis, in Queensland. University of Sydney, Sydney.

Milne D. J. & Pavey C. R. (2011) *The status and conservation of bats in the Northern Territory*.

Moseby K. E., Brandle R. & Adams M. (1999) Distribution, habitat and conservation status of the rare dusky hopping-mouse, Notomys fuscus (Rodentia : Muridae). *Wildlife Research* 26, 479-94.

Moseby K. E. & Kemper C. (2008) Pseudomys australis. The IUCN Red List of Threatened Species. Version 2014.2, www.iucnredlist.org.

Noble J. C., Muller W. J., Detling J. K. & Pfitzner G. H. (2007) Landscape ecology of the burrowing bettong: Warren distribution and patch dynamics in semiarid eastern Australia. *Austral Ecology* 32, 326-37.

Pavey C. R., Nano C. E. M., Cooper S. J. B., Cole J. R. & McDonald P. J. (2011) Habitat use, population dynamics and species identification of mulgara, Dasycercus blythi and D. cristicauda, in a zone of sympatry in central Australia. *Australian Journal of Zoology* 59, 156-69.

Perry J., Fisher A. & Palmer C. (2011) Status and habitat of the Carpentarian Grasswren (Amytornis dorotheae) in the Northern Territory. *Emu* 111, 155-61.

Seabrook L., McAlpine C., Baxter G., Rhodes J., Bradley A. & Lunney D. (2011) Drought-driven change in wildlife distribution and numbers: a case study of koalas in south west Queensland. *Wildlife Research* 38, 509-24.

NSW National Parks & Wildlife Service (NSW NPWS) (2002) Plains-wanderer (*Pedionomus torquatus*) Draft Recovery Plan. NSW National Parks and Wildlife Service, Dubbo.

Wilson S. & Swan G. (2010) *A complete guide to reptiles of Australia*. New Holland, Sydney.

Woinarski J. C. Z., Burbidge A. A. & Harrison P. (2014) *The action plan for Australian mammals 2012*. CSIRO Publishing, Collingwood.

Woinarski J. C. Z. & Legge S. (2013) The impacts of fire on birds in Australia's tropical savannas. *Emu* 113, 319-52.