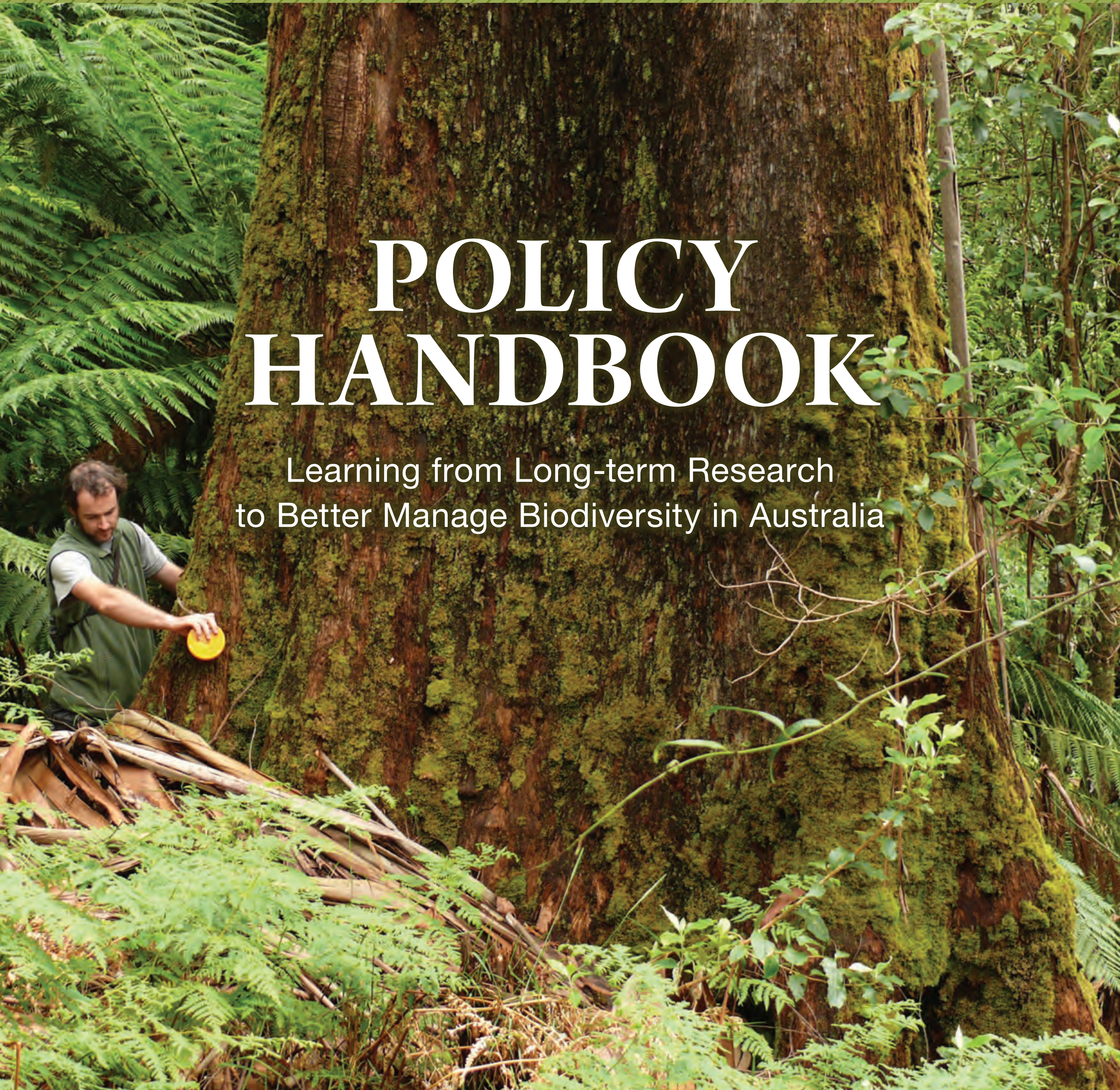
POLICY HANDBOOK

Learning from Long-term Research to Better Manage Biodiversity in Australia



Emma Burns and David Lindenmayer

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Learning from Long-term Research to Better Manage Biodiversity in Australia

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TERN
Terrestrial Ecosystem Research Network

LTERN
Long Term Ecological Research Network

A landmark project was undertaken from late 2011 until late 2013 involving 84 contributing environmental professionals (primarily ecological scientists). The task was to develop a cohesive book that described changes in a range of Australian ecosystems that have been subject to detailed long-term research. The overarching purpose of these long-term studies has been to document the changes, identify the drivers of change and provide the evidence and knowledge needed to inform better natural resource management in Australia.

This handbook describes the key findings and messages from that long-term ecological research for policy makers and the general public. Please cite original book chapters where appropriate.

The book

Lindenmayer D, Burns E, Thurgate N, Lowe A (Eds) (2014) 'Biodiversity and Environmental Change: Monitoring, Challenges and Direction'. (CSIRO Publishing: Melbourne.) Available at: <http://www.publish.csiro.au/nid/21/pid/7009.htm>.

National Library of Australia Cataloguing-in-Publication entry

Burns, Emma, author.

Policy handbook: learning from long-term research to better manage biodiversity in Australia/Emma Burns, David Lindenmayer.

9781486300457 (paperback)

Biodiversity conservation – Australia
Environmental monitoring – Australia.
Environmental management – Australia.

Lindenmayer, David, author.

363.7063

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

Telephone: +61 3 9662 7666
Local call: 1300 788 000 (Australia only)

Fax: +61 3 9662 7555
Email: publishing.sales@csiro.au
Website: www.publish.csiro.au

Cover: Photos from the field – a collection of images from research sites within the Long Term Ecological Research Network. People, data, science and knowledge are central drivers within the Long Term Ecological Research Network. Front cover photo by: David Blair. Back cover photos by (clockwise from top left): Chris MacGregor, Dan Metcalfe, Peter Green, Tim Arch, Henrik Wahren, Alan Kwok.

Set in 11/14 Adobe Helvetica Neue LT Std and Adobe Caslon Pro
Edited by Peter Storer Editorial Services
Cover design by Andrew Weatherill
Typeset by Desktop Concepts Pty Ltd, Melbourne
Printed in Australia by Metro

Acknowledgements

This document (and the book) was supported by the Australian Government's Terrestrial Ecosystem Research Network (www.tern.org.au). This is an Australian research infrastructure facility established under the National Collaborative Research Infrastructure Strategy and Education Infrastructure Fund–Super Science Initiative through the Department of Industry (formerly the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education). TERN has catalysed collaborations between researchers dedicated to ecological research and who would have been unlikely to work together without support from TERN.

First we would like to thank Philip Tennant and Suzanne Long for their reviews of this handbook, which improved the end product. We are also indebted to Suzanne for drafting the executive summary. Natasha Purvis, Kathryn Nolan, Claire Shepherd and Tracey Millen also helped with the production of this handbook. Finally, we thank all book contributors and our co-editors Nicole Thurgate and Andrew Lowe. The book comprised 14 chapters, all with multiple authors. In addition to chapter authors, others wrote feature boxes by invitation to highlight additional critical information. The following is a list of all book contributors: Sarah Barrett, Sam Banks, Gary Bastin, Andrew Bennett, David Bowman, Matt Bradford, Emma Burns, James Camac, Guy Castley, Tim Clancy, Michael Clarke, Mark Cowan, Mason Crane, Beth Crase, Chris Dickman, Eleanor Dormontt, Nicki de Preu, Andrew Edwards, Glenn Edwards, Neal Enright, Emilie Ens, Alaric Fisher, Jeff Foulkes, Barry Fox, Peter Green, Pauline Grierson, Greg Guerin, Sam Harburg, Dean Heinze, Jean-Marc Hero, David Hilbert, Ary Hoffman, Joanne Isaac, Geoff Kay, David Keith, Mike Lawes, Michael Liddell, David Lindenmayer, Greg Lollback, Andrew Lowe, Fran MacGillivray, Adrian Manning, Ian Mansergh, Keith McDougall, Daniel Metcalfe, Damian Michael, Rebecca Montague-Drake, John Morgan, Katherine Moseby, Helen Murphy, Brett Murphy, Michael Nash, Paul Novelly, Sachiko Okada, David Orr, Warick Papst, David Paton, Scott Parsons, Stuart Phinn, Kylie Piper, Lynda Prior, Suzanne Prober, John Read, Richard Robinson, Suzanne Shearer, Jon Shuker, Russell Sinclair, Jeremy Russell-Smith, Ben Sparrow, Alison Specht, Nicole Thurgate, Mark Tozer, Stephen Van Leeuwen, Henrick Wahren, Tim Wardlaw, Glenda Wardle, Justin Welbergen, David Westcott, Andrew White, Stephen Williams, Richard Williams, John Woinarski, Samuel Wood and Colin Yates.

Executive summary

Australia's unique and diverse ecosystems are of enormous intrinsic, scientific and economic value. Their healthy functioning delivers the fundamental ecosystem services – water, air, soils – upon which our communities and industries depend. Unfortunately, this country has a very poor record of successfully using scientific knowledge to inform ecosystem management.

In an attempt to facilitate a more effective pathway from ecological knowledge through to environmental action, 84 environmental professionals have synthesised the findings of their ecological monitoring and research projects throughout Australia into a single large volume. The book demonstrates unequivocally how Australia's ecosystems have changed. The book integrates and generalises information at scales relevant for leaders and policy makers. This policy handbook is a guide to some of the most important conclusions in that volume.

At the continental scale, the most urgent threats to Australian ecosystems are:

- changes in the frequency and severity of fire
- grazing by livestock (and over-abundant native herbivores)
- clearing and fragmentation of remaining native vegetation
- plant disease
- increased nutrients in ecosystems
- invasive plants and animals
- soil disturbance
- dryland salinity
- tourism (infrastructure and accidental pest introduction)
- removal of dingoes
- bio-prospecting and mining (and associated exploration activities)
- altered hydrological regimes
- climate change.

Ecosystem-specific management recommendations to tackle these threats are provided herein.

It is time to act more effectively to tackle Australia's environmental challenges. The collaborative research infrastructure that is providing critical insights into ecosystem threats and their management needs to be maintained in the long term. Ecologists must make even greater efforts to collaborate and deliver policy-relevant knowledge, and policy makers and managers need to access, understand and use this knowledge.

FIG. 1. *Desert storm* (photo by Aaron Greenville)

Introduction

Ecology is the study of nature and the interactions and dependencies of organisms with the environment. The science of ecology is conducted through experiments and observations where data are collected and analysed to explain or predict patterns in the environment.

Over recent decades, there has been a burgeoning of many different ecological fields such as landscape ecology, restoration ecology, ecological modelling, conservation biology, conservation genetics, phylogeography and others. During this time, the number of scientific papers published in ecology has increased enormously.

Despite the proliferation of ecological research, frustratingly few generalisations can be made from this body of scientific effort, aside from the obvious present trend that many elements of the biota are diminishing, with a concomitant reduced capacity of ecosystems to sustain ever-increasing human populations. The shortage of generalisations in ecology is primarily because nature has such great diversity and also because the extent and duration of individual research projects are usually insufficient to answer large-scale questions. For example, most research is conducted over 1- to 3-year periods and at a local scale. This shortage of generalisations is an inconvenient truth for leaders and policy makers responsible for informing and steering societies so that they are ecologically sustainable, healthy and happy. None of these goals can be achieved without environmental services that continue to provide food, water and shelter.

To help facilitate a more effective pathway from ecological knowledge through to environmental action we have written this handbook in a simple and clear way. In the following sections, we present information from *Biodiversity and Environmental Change: Monitoring, Challenges and Direction* ('the book') for a non-scientific audience. Written by some of Australia's most active and eminent ecologists, the book describes and communicates ecological science undertaken over the last 10–80 years in nine different Australian ecosystems.

This handbook has two key components: (1) a series of numbered feature boxes (in grey) which summarise key concepts, information and issues that feature in the book; and (2) summaries for each of the nine ecosystems discussed in the book. For each ecosystem, there are two coloured feature boxes: a summary of the key discoveries from the research (in blue) and priority management recommendations (in orange). For each ecosystem, detailed information is available from the corresponding book chapter.

Box 1. What is TERN?

TERN (the Terrestrial Ecosystem Research Network, www.tern.org.au) is a data collection, storage and sharing infrastructure network for Australian ecosystem science. TERN is fostering national networks of scientists, environmental managers and stakeholders to improve understanding and management of Australia's ecosystems. Most research summarised in this handbook is drawn from work by scientists from five key components within TERN:

- Ausplots Rangelands – a new continental network of surveillance monitoring plots in rangelands
- Ausplots Forests – a new large-scale network of surveillance monitoring plots in tall eucalypt forests
- The Australian Transect Network – a network of new and established monitoring transects spanning environmental gradients
- The Long Term Ecological Research Network – built on pre-existing long-term terrestrial ecology research plot networks
- The Australian Supersite Network – a series of new and established sites undertaking intensive ecosystem measurements.

Box 2. What is a core study?

The research described in each ecosystem in this handbook is drawn from core studies. In the majority of cases, core studies were established by one or more of the chapter authors and are examples of long-term ecological monitoring and research. More specifically, they consist primarily of a series of monitoring plots (see Fig. 2) that are visited repeatedly over long time periods. At each visit, environmental information is collected in a consistent way. This information often includes data about the plants, animals, soil, water and climate. This repeated measurement of data from the plots allows researchers to examine environmental trends over time.

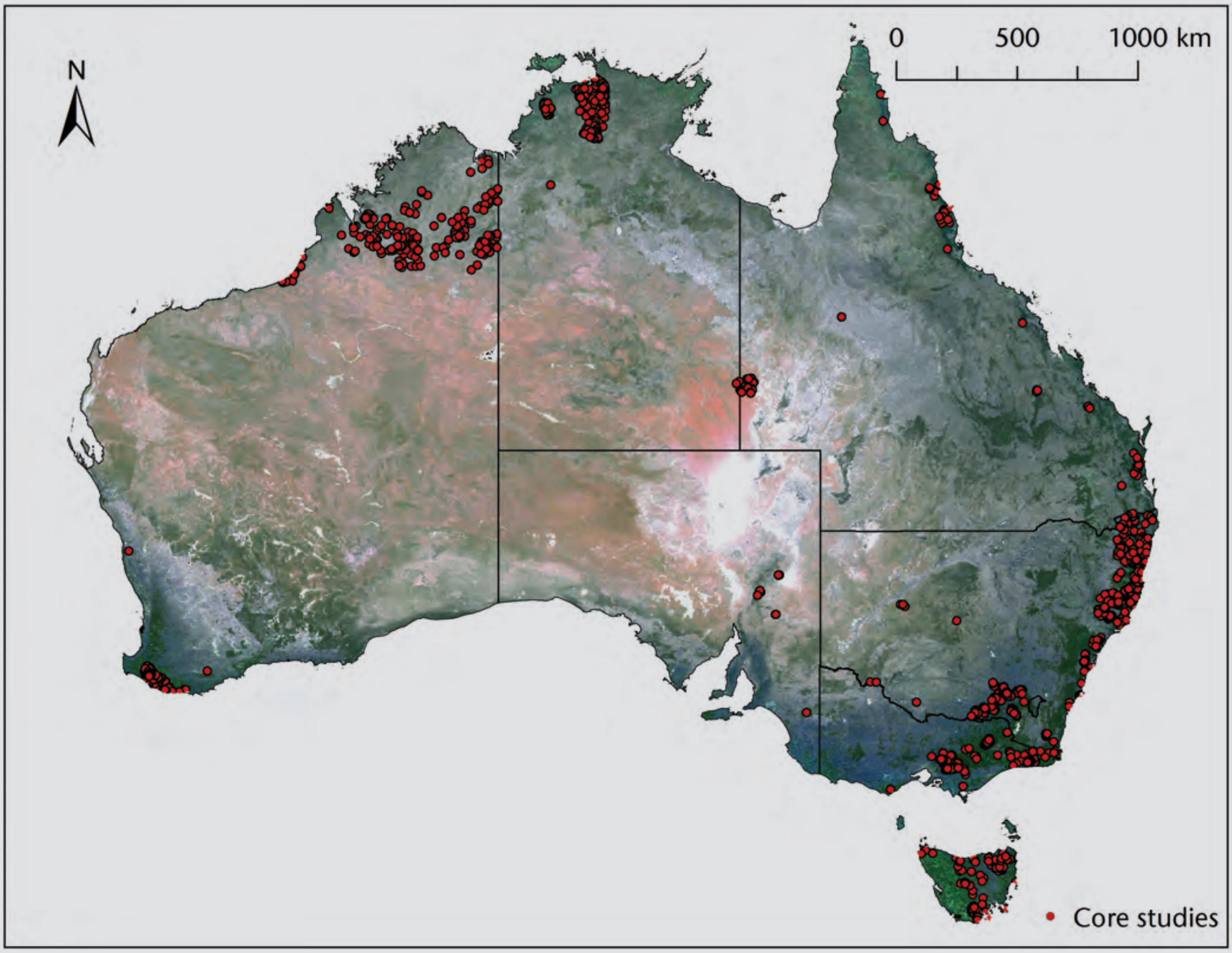

FIG. 2. *The location of monitoring plots that form the 35 core studies used to examine and discuss environmental trends* (map prepared by Eleanor Dormontt)

Essential concepts and messages

Box 3. What are ecosystems and ecosystem processes, drivers and threats?

Ecologists frequently talk of ecosystems, ecosystem processes, drivers and threats. An **ecosystem** refers to the living organisms (animals, plants, fungi, bacteria and other microbes) and non-living elements (soil, water, climate, etc.) of a specific area that interact and depend upon one another to varying degrees. Ecosystems can vary in scale: for example, a local pond is an ecosystem but so is an extensive region dominated by rainforest. Although here and in the book we refer to discrete ecosystems, in reality ecosystems are not tightly defined and bounded, but rather they overlap with each other.

Ecosystem processes are the dynamic interactions between organisms and their environment. Ecosystems can fail to remain functional if these processes are altered significantly. An **ecosystem driver** is a critical process that influences the functioning of the ecosystem. Examples of ecosystem drivers are fire, soil type, native grazing and climate. A **threat** is a process that has an anthropogenic element that is changing ecosystem function. Key examples are altered fire regimes, exotic plants and animals, and native vegetation clearance.

Understanding the processes giving rise to patterns of change in an ecosystem is critical to understanding how an ecosystem functions and what management strategies will be effective in retaining these functions.

One important feature of the book is that authors have developed and/or modified existing conceptual models to explain the drivers and threats in the ecosystems they study. These conceptual models communicate the key processes that shape different ecosystems, the interdependencies between those processes, the direction of their effects, as well as their likely response to alternative management approaches.

Box 4. There is substantial value in systematic and prolonged ecological research

In the book, five primary values of long-term ecological research are discussed and examples from the research are provided. These values are:

1. quantifying ecological responses to environmental change (natural and/or anthropogenic)
2. understanding complex ecosystem phenomena that occur over a prolonged period
3. providing core ecological data for use in developing theoretical models and in setting parameters for and validating simulation models
4. acting as platforms for collaborative studies, thus promoting multi- and inter-disciplinary research
5. providing data and understanding to support evidence-based policy, decision making and management of ecosystems.

To understand the dynamics of a given ecosystem, and the plant and animal populations it supports, that ecosystem needs to be carefully studied over prolonged periods. This is because the relationships that underpin ecosystem dynamics are often complex, non-linear, and can vary at different spatial and time scales. Consequently, it can be difficult to determine what the drivers influencing environmental change within an ecosystem are, and frequently there is more than one cause contributing to a change in an ecosystem.

For example, monitoring in the tropical savannas of northern Australia is revealing a significant decline in small mammal populations and, although altered fire regimes and exotic animals have been implicated, how these factors (and others) are interacting to influence the decline is not yet well understood. In other cases the answers are clear. For example, data from the long-term monitoring sites in the alpine ecosystem provide clear insights into the profound impacts of domestic livestock grazing on alpine ecosystems. Because livestock selectively eat particular plants and not others, this is changing which plants are present and where they occur. This, in combination with the physical damage from the hard hooves of livestock, leads to increases in shrub cover. And because shrubs are more flammable than the grasses that the stock like to eat, livestock grazing has the unforeseen effect of actually increasing fire severity in alpine ecosystems. Importantly, research also shows that these grazing effects can be reversed and that land condition and conservation values improve (albeit relatively slowly) if livestock are removed.

Because understanding ecosystems requires time, existing long-term studies are a critical part of Australia's environmental infrastructure and need to be maintained. The value of each individual study featured in the book relies heavily on the implementation of systematic field protocols to explore patterns in biodiversity over time. Across the network of plots and experiments, we are able to examine, and then document, how the Australian environment is changing and what the causes of change are likely to be. Strengthening our understanding of ecological interactions and processes will enable us to better predict how they will respond to a changing climate and inform future management.

Box 5. It is not all bad news

The findings of ecological research commonly document declines in biodiversity. However, there are also many positive stories. The value of replanted areas for conserving woodland birds is one of several examples from the research highlighted in the book. Some other examples include:

- Rainforests: In the rainforests of eastern Australia, some replanting schemes have been restoring community structure and reducing microclimatic extremes.
- Alpine: In the Victorian alps, research on the ecology and genetics of the Mountain Pygmy Possum has informed what presently appear to be effective conservation management strategies. At Mount Buller ski resort, the population collapsed due to habitat destruction and fragmentation within the resort, resulting in a dramatic loss of genetic variation. However, in 2010 and 2011, translocation of males from the Mount Higginbotham population allowed cross-breeding between populations to promote the restoration of genetic diversity. Also, experimental investigations of the potential impacts of climate change on alpine ecosystems indicate a capacity for some plants to genetically adapt to warming. This indicates a degree of resilience to a 1–2°C increase in mean annual temperature over the coming decade.
- Heathland: In recent decades, plant and animal species in Australian heathlands have exhibited a capacity to recover after fire and mining. For example, fire-related losses of diversity have so far been localised and transient, and small mammal populations are recovering in sandplain heathlands that were restored after sandmining.

It is important to highlight and examine positive stories because much can be learned from successful ecosystem management.

Box 6. Our research is not spatially comprehensive but is nevertheless highly informative

The chapters of the book provide an overview of how elements of the environment are changing over time, including in response to management interventions (e.g. vegetation restoration and control of invasive plants and animals) and disturbance regimes, such as fire, grazing and logging. The book draws on 35 core studies, as well as numerous additional studies in providing these overviews.

The majority of the research has occurred systematically over prolonged periods. Although the spatial coverage of the research is neither comprehensive or representative (see Fig. 2), ecosystem processes relevant to management have been elucidated. The spatial distribution of the core studies is the focus of a chapter in the book. A key finding from the analysis undertaken was that areas with higher human population densities and greater economic importance have the most long-term ecological monitoring. These areas also generally experience higher environmental pressures and stand to benefit from effective monitoring to inform appropriate management actions. In contrast, vast, remote, arid areas of Australia (and the vegetation communities that dominate this region) are generally poorly sampled.

Beyond the importance of the individual studies, there is also potential to use information from across these studies. For example, analyses could be undertaken to contrast patterns in long-term datasets drawn from different studies. This kind of work has the potential to reveal new insights into patterns of change across ecosystems.

Tropical rainforests of eastern Australia

Chapter authors: Daniel Metcalfe, Michael Liddell, Matt Bradford and Peter Green

Ecosystem overview

The tropical rainforests of eastern Australia comprise about 0.2% of the Australian landmass. The current condition and extent of tropical rainforests of eastern Australia is the result of a wide range of natural and human-derived factors. Despite over 100 years of clearing and exploitation, tropical rainforests continue to support a huge range of biodiversity. Lowland rainforest has largely been cleared for agriculture, but most remaining remnant rainforest is now protected.

FIG. 3. The 47 m tall Australian Canopy Crane at the Daintree Rainforest Observatory provides scientists with canopy access across a 1-ha area of lowland rainforest (photos by P Byrnes)

The research

This chapter synthesises a new understanding of the dynamics of tropical rainforests that has been generated from three core studies, along with other studies. The research is showing that there is a slow erosion of biodiversity values in these rainforests due to the combined pressures of habitat clearance and fragmentation, the introduction of exotic pests and diseases, and climate change.

Study name	Data collected	Start year	Current status
Tropical Rainforest Plot Network	Plants and vegetation structure	1971	Ongoing
Connell Rainforest Plot Network	Plants and vegetation structure	1963	Ongoing
Daintree Rainforest Observatory	Plants and vegetation structure	1999	Ongoing

Key discoveries

- Monitoring trees over 35 years has shown that increased temperatures result in higher growth rates of trees but also in higher mortality rates. However, they are not affecting recruitment. This suggests that climate change could result in a net reduction in carbon storage in mature forests, rather than the increase in storage predicted from analyses of growth data alone.
- Ten years of distributional data for bird communities show that climate warming is making assemblages at given elevations more like those at lower elevations. Continued monitoring will be important to understand how these assemblages respond to ongoing warming and particularly what the impact is on the species restricted to the highest altitudes.
- Dieback episodes caused by diseases such as *Phytophthora* cause massive short-term effects, but rainforests appear relatively resilient, with increased growth and recruitment rates in response to initial mortality.
- Monitoring of the impacts of tropical cyclones Larry and Yasi on seedling communities shows that the initial pulse of herbaceous species dies out within about 3 years, and is overtaken by natural regeneration of native species. However, a few woody species have the ability to persist in the understorey despite this competition and they are then able to respond rapidly to subsequent disturbance events.
- Long-term monitoring across many sites emphasises that natural disturbances (cyclones, disease, fire, flood and drought) trigger flowering, fruiting and recruitment events. These events maintain structural and species complexity, provided that there is sufficient adjacent habitat to provide seed or propagule sources, and animal disperser communities.
- Nine years of monitoring of flying fox camps and movement patterns show these animals are nomadic, capable of travelling huge distances and are not restricted in diet to rainforest fruits. This fundamentally changes our understanding of flying fox population dynamics and consequently the options available to attempt management of them.

Key management recommendations

- High severity but infrequent natural disturbances such as cyclones are unlikely to have catastrophic negative long-term impacts on rainforest ecosystems and rainforest biodiversity, provided that: (1) remnant vegetation is sufficiently extensive to support animal populations and provide seed sources; and (2) links between fragments are created or maintained to facilitate dispersal.
- Weed management is best targeted at those woody species capable of establishing in post-cyclone conditions and then persisting until subsequent disturbances provide opportunities for expansion. These species pose the greatest risk to rainforest integrity in the long term, so early intervention potentially saves significant future costs.
- Fire is both a management tool and a threatening process – it needs to be used judiciously at the correct time in the correct place.
- Rainforests and the species they support have moved across the landscape in past millennia, and current work reinforces our understanding of these dynamics and the central role of refugial areas. Conservation of predicted refugial areas under climate change scenarios should be a priority in ensuring that rainforest communities are as resilient as possible in the face of current and future threats.
- Caution should be employed in anticipating the responses of vertebrates and invertebrates to changes in natural conditions or imposed management. This is because we have a limited understanding of the ecology of many vertebrate and most invertebrate groups, including communities of pollinator and decomposer organisms. Ongoing studies confirm the extraordinary diversity and complexity of rainforest animal communities and the subtlety of their responses to change. Management should consider a precautionary approach in making interventions with potentially significant effects on communities or species with restricted ranges or habitat requirements.

Alpine ecosystems

Chapter authors: Richard Williams, Warwick Papst, Keith McDougall, Ian Mansergh, Dean Heinze, James Camac, Michael Nash, John Morgan and Ary Hoffmann

Ecosystem overview

Alpine landscapes occupy roughly 0.04% of the Australian continent and are of national and international significance because of their tectonic, geomorphic, biotic and cultural values. The term ‘alpine’ refers to the treeless vegetation above the climatic limit of tree growth. On mainland Australia, the treeline occurs at about 1700–1900 m above sea level, and at about 1000 m in Tasmania. However, trees and treeless vegetation may occur in a mosaic near the upper treeline and the treeline may be inverted in valleys. The majority of Australia’s alpine ecosystems are now protected. However, recreational uses of the alpine landscape, such as skiing, bushwalking and other outdoor adventure activities, have increased.

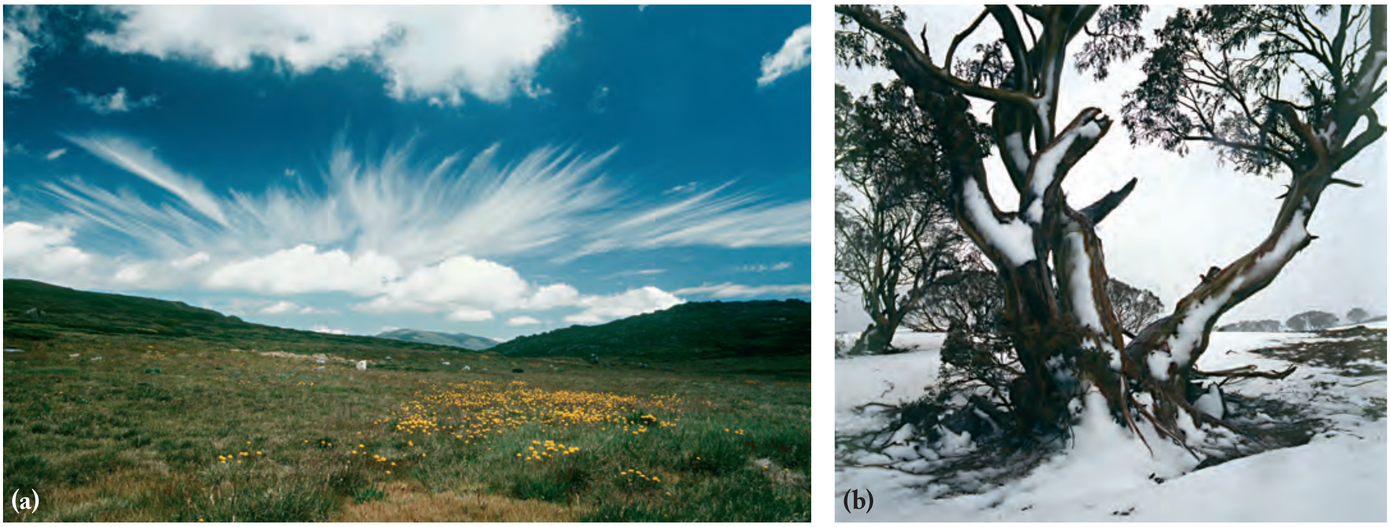

FIG. 4. The alpine environment of the Bogong High Plains: (a) treeless vegetation above the treeline in summer; (b) the high subalpine environment in winter, with treeless vegetation in mosaic with stands of snow gum (Eucalyptus pauciflora) (photos by Colin Totterdell)

The research

Ecological research has been undertaken in the Australian alpine ecosystem for many decades, with monitoring plots in all major plant communities, some of which date from the 1940s. The alpine chapter in the book synthesises the learnings from four core studies, along with other studies.

The core studies relate to long-term research on vegetation dynamics, the biology of the Mountain Pygmy Possum, post-fire regeneration and climate change impacts. The plot network has made it possible to study the effects of land use on soils and vegetation, interpreting the patterns of ecological change following major fires, anticipating potential ecological response to climate change, and identifying and managing the invasion of exotic species.

Study name	Data collected	Start year	Current status
Victorian Alpine Plot Network; Vegetation plots	Plants and vegetation structure	1946	Ongoing
Victorian Alpine Plot Network; *Burramys* sites	Small mammal population numbers; sex, age, weight	1982	Ongoing
Victorian Alpine Plot Network; post-fire vegetation plots	Plants and vegetation structure	1998	Ongoing
Victorian Alpine Plot Network; Australian Tundra Experiment and Phenology sites	Microclimate, plants and vegetation structure, phenology (i.e. plant and animal cyclic events), invertebrates	2003	Ongoing

Key discoveries

- Long-term vegetation change is a feature of alpine ecosystems, and documenting this has been a focus of research in the Australian Alps. Changes in the composition of shrubs, grasses and forbs can be substantial, and depend on interactions between disturbance and species life history.
- The conservation management of the Mountain Pygmy Possum is a success story for long-term ecological research and landscape management.
- Ungulates (hard-hooved animals) such as cattle, sheep, horses, deer and pigs have had substantial deleterious effects on alpine ecosystems. These include removal of vegetation cover, reduction in the cover of palatable plants through selective grazing and trampling of rare plant communities such as Sphagnum bogs and snow-patch herbfields.
- Alpine vegetation of mainland Australia has a strong capacity to regenerate after large and severe fires such as those in 2003.
- Grazing by domestic livestock does not reduce the incidence or severity of fire in Australian alpine ecosystems.
- Alpine grasslands and open heathlands appear to be resilient to warming of 1–2°C over the coming decade.
- Exotic, invasive plants and animals pose a clear and present major threat to alpine ecosystems and are likely to increase in abundance as a consequence of climate change.
- Assessing the potential effects of climate change on alpine ecosystems, and interpreting the patterns of ecological change following landscape-scale fires such as those in 2003, would not have been possible without long-term monitoring plots.

Key management recommendations

- Weeds and feral animals are the most pressing threats in Australian alpine ecosystems. While existing populations require control, early detection and eradication of founder populations is urgently needed. Appropriate monitoring and eradication protocols are needed.
- Hooved animals should be removed from all Australian alpine ecosystems to allow natural regeneration to occur.
- Maintain the existing network of long-term monitoring plots so that: (1) potential effects of climate change and land use change can be interpreted in the light of long-term environmental change; and (2) such knowledge can guide management decisions.
- Governments should support programs to monitor the state of rare species of plants and animals.
- Develop partnerships and protocols that allow ecological knowledge gained from long-term research to be evaluated and applied in land management.

Heathlands

Chapter authors: David Keith, David Lindenmayer, Andrew Lowe, Jeremy Russell-Smith, Sarah Barrett, Neal Enright, Barry Fox, Greg Guerin, David Paton, Mark Tozer and Colin Yates

Ecosystem overview

In Australia, heathlands occupy a relatively small portion of the continent, covering approximately 1.3–1.9% of the land mass. They are scattered widely around the nation's coast and associated hinterlands and ranges. Typically, trees are absent or are sparsely scattered and rarely exceed 10 m in height. Heathlands are major repositories of Australia's unique and iconic flora and also support a specialised fauna. Often situated within spectacular scenic landscapes, heathlands provide an important focus for the ecotourism industry. Although heathlands are comparatively well represented within protected areas, they are subject to ongoing threats from land clearing and associated degradation, inappropriate fire regimes, climate change and plant disease. Several heathland communities are listed as threatened under Commonwealth and/or state legislation.

FIG. 5. (a) Heath banksia, a dominant shrub of heathlands in the Sydney Basin (photo by David Keith)*; (b) Leichhardt's Grasshopper basking on its host plant, a shrub species of foxglove* (photo by Piers Barrow)

The research

There has been considerable ecological research in heathlands over the past 60 years and 11 core studies (along with others) are described in the book. This long-term research has produced significant insights into the causes of changes in heathland biodiversity, which could not otherwise have been detected and diagnosed.

Study name	Data collected	Start year	Current status
Upland Heath Swamps Plot Network	Plants	1983	Ongoing
Jibbon heath and *Xanthorrhoea* population study	Plants	1989	Ongoing
Jervis Bay Booderee National Park Plot Network	Vertebrate animals	2002	Ongoing
Three Parks Savanna Fire-Effects Plot Network	Vertebrate animals and invertebrates	1994	Ongoing
Myall Lakes small mammal fire study	Small mammals and vegetation structure	1974	Inactive since 1998
Myall Lakes small mammal mining study	Animals and vegetation structure	1982	Inactive
Barren Grounds Ground Parrot study	Birds	1983	Inactive since 2009
Eneabba sandplain Banksia study	Plants	1986	Ongoing
Ngarkat fauna and nectar study	Plants and animals	1990	Ongoing
Stirling Range *Phytophthora* and fire study	Plants	1997	Ongoing
Phytophthora study	Plants	1996	Ongoing

Key discoveries

Several major discoveries in heathlands could not have been made without long-term ecological research. Four of these are:

- Contrasting fire regimes are driving different trends in heathland plants and animals in different parts of the continent, with responses depending on intervals between successive fires, characteristics of individual fires and the life histories and habitat requirements of individual species. Declines in heathland biodiversity are reversible, provided managers are able to avoid widespread recurrence of fire regimes associated with the declines.
- Root-rot disease caused by an invasive pathogen, a soil-borne water mould known as Cinnamon Fungus, is causing rapid declines in susceptible plant species, with associated transformations of vegetation structure, animal habitats and food sources. The declines are most extreme in temperate heathlands with winter-dominated rainfall. Disease treatments have been partially effective in some regions, but a major research initiative is needed to develop new and more effective management strategies to mitigate ongoing losses of heathland diversity.
- Loss of heathland habitat from land clearing has been unevenly distributed across the continent. Expansion of cropping, sandmining and urban coastal development is primarily responsible for habitat loss. Restoration of sandmined areas has been successful in promoting the re-establishment of some ground mammal species, albeit at a slower rate than occurs after fire. Restoration of the full diversity of native plant communities following clearing continues to be limited and problematic.
- Long-term studies show that anthropogenic climate change is having an impact on heathland ecosystems, with recent reductions in regional rainfall of up to 30% associated with reduced survival, slower growth and reduced flower production in key shrub species. This will have consequences for plant regeneration from seed and availability of food for nectar-dependent birds and mammals. Other potential effects of climate change relate to changes in the frequency of extreme weather, but more long-term study is needed to resolve trends and viable adaptation strategies, which will likely vary between locations.

Key management recommendations

- Establish a national initiative to develop and evaluate new treatments and management techniques for control of root-rot disease caused by *Phytophthora cinnamomi*, expanding on actions in the current Threat Abatement Plan http://www.environment.gov.au/biodiversity/threatened/publications/tap/phytophthora.html.
- Improve coverage of the National Reserve System to include poorly represented heathland types and protect fragments containing unique or significant features, especially in the south-west Australian wheatbelt and the Kimberley coast.
- Develop new management techniques to restore and secure heathland ecosystems degraded by past land uses or encroaching new land uses, particularly where degradation involves nutrient enrichment.
- Develop fire management strategies that promote persistence of local plant and animal assemblages and are responsive to regional fire regimes and management settings. For example, heathlands in urban and wild landscapes will require different management approaches, while tropical and temperate heathlands will require contrasting fire management strategies to accommodate the life histories of their component species.
- Invest in long-term studies and field experiments to improve understanding of the ecological mechanisms underpinning heathland responses to climate change to support development of adaptation strategies and strengthen mitigation policy.

Temperate eucalypt woodlands

Chapter authors: David Lindenmayer, Suzanne Prober, Mason Crane, Damian Michael, Sachiko Okada, Geoff Kay, David Keith, Rebecca Montague-Drake and Emma Burns

Ecosystem overview

Temperate woodlands encompass many ecological communities, habitats and species of national and global significance. They can generally be thought of as the interface between taller, wetter forested areas on the coast and the drier, hotter grasslands and shrublands of the interior. They are typically characterised by widely spaced trees and a ground layer of grasses and wildflowers. These woodlands are some of the most extensively cleared, heavily modified and highly degraded vegetation types in Australia. This is, in part, because of the suitability of these areas for cropping and/or grazing by domestic livestock. Land-use intensification and ongoing transformation to support agricultural and other developments has resulted in the loss of about 75% of these woodlands across the continent.

FIG. 6. *(a) The Mulligans Flat–Goorooyarroo Woodland Experiment where exclusion fences reduce kangaroo grazing* (photo by Adrian Manning)*; (b) a scattered paddock tree landscape near Ladysmith in southern New South Wales* (photo by David Lindenmayer)

The research

Temperate eucalypt woodlands have been the focus of considerable ecological research and management, although there are relatively few long-term studies in these ecosystems. In the book, the learnings from three core studies – all located in southern New South Wales – are synthesised, along with several other shorter studies. Long-term data gathering has led to critical new insights about the ecology, conservation and management of temperate eucalypt woodlands. The knowledge generated is important for guiding major conservation and resource management investments such as restoration and grazing control programs. These initiatives can exceed billions of dollars in investment, with little environmental return if not executed well.

Study name	Data collected	Start year	Current status
Nanangroe Plantation Plot Network	Plants, animals and vegetation structure	1997	Ongoing
South West Slopes Restoration Study	Plants, animals and vegetation structure	2000	Ongoing
Woodland Restoration Plot Network (Cumberland Plain)	Plants, animals and vegetation structure	1992	Ongoing

Key discoveries

- Detection rates of some species of temperate woodland birds in southern New South Wales have increased over the past decade, including several which were previously considered to be declining, such as the Brown Treecreeper and Superb Parrot.
- Both re-planted temperate woodland and natural regrowth temperate woodland are important habitats for birds and reptiles, including a range of species of conservation concern. Such areas support a significantly different (but also complementary) assemblage of birds to old-growth woodland, particularly small-bodied, non-seed eating birds.
- Interventions such as grazing control lead to improvements in vegetation condition and these changes can, in turn, have positive impacts on temperate woodland birds.
- Temporal changes in plant species composition in revegetated temperate woodland areas can be on a different trajectory to that of ‘natural’ vegetation.

Key management recommendations

There are many prescriptions for the management of temperate eucalypt woodland that would be specific for particular locations and special habitats (e.g. granite outcrops). Rather than create an extensive list of such specific recommendations, we outline below a small number of generic recommendations that will be broadly applicable across the vast majority of areas of temperate eucalypt woodland. These are:

- Establish additional conservation initiatives focused on private land. There is a particular need to support incentive programs that prevent clearing of temperate eucalypt woodlands and control damaging grazing regimes such as high-intensity set stocking.
- Maintain funding schemes that are clearly leading to successful outcomes, such as those that have catalysed major restoration efforts – both natural regeneration and replanting.
- Secure the protection of the network of Travelling Stock Reserves in New South Wales and Queensland.

Northern Australian tropical savannas

Chapter authors: Jeremy Russell-Smith, Andrew Edwards, John Woinarski, Alaric Fisher, Brett Murphy, Mike Lawes, Beth Crase and Nicole Thurgate

Ecosystem overview

Tropical savannas typically consist of an open tree layer with a continuous grassy ground layer. They cover the majority of northern Australia – approximately a quarter of the Australian continent. They experience highly seasonal rainfall and mean annual rainfall is generally too low to support crop-based agriculture (<600 mm). For the most part, these savannas are used for rangeland beef cattle production. However, much of the savanna is, at best, economically marginal for pastoral production given the concurrence of low fertility soils, seasonally scarce water supplies, and distant and vicarious markets. Beyond major urban settlements, the human population is very sparse, comprising mostly Aboriginal people. Despite the appearance of being relatively unmodified, it is increasingly recognised that contemporary land uses and changed fire regimes in the savannas are having significant regional impacts on biodiversity, greenhouse gas emissions and carbon storage.

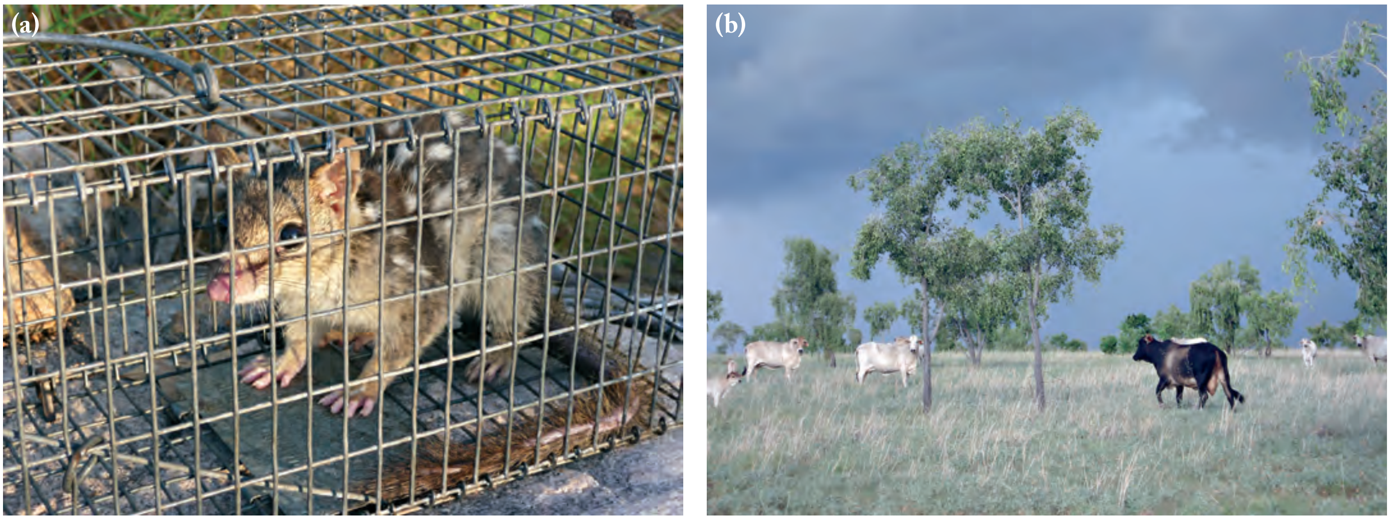

FIG. 7. (a) Northern quoll captured in a cage trap. Although already in decline, fauna monitoring demonstrated the rapid disappearance of quolls from most sites in Kakadu following the arrival of cane toads (photo courtesy of Northern Territory Government)*; (b) cattle grazing on Northern Territory savanna* (photo by Andrew White)

The research

The book discusses three core studies that primarily examine the role of fire in tropical savannas and makes references to other studies. The three core studies are all based in the Northern Territory and are part of the Three Parks Savanna Fire-Effects Plot Network, which was established with the primary aim of training management staff and assisting with the development of adaptive approaches to conservation-based fire management in regional savanna systems. The program combines remote sensing of fires with a network of 220 permanent plots. In addition, data assembled from the plot network have been instrumental in developing savanna burning carbon accounting methodologies.

Study name	Data collected	Start year	Current status
Three Parks Savanna Fire-Effects Plot Network (Kakadu)	Plants, animals, vegetation structure, fire occurrence and severity	1994	Ongoing
Three Parks Savanna Fire-Effects Plot Network (Litchfield)	Plants, animals, vegetation structure, fire occurrence and severity	1995	Ongoing
Three Parks Savanna Fire-Effects Plot Network (Nitmiluk)	Plants, animals, vegetation structure, fire occurrence and severity	1995	Ongoing

Key discoveries

- The small mammal fauna is in significant decline in the Top End of the Northern Territory. This decline is attributable, at least in part, to frequent fires.
- Declines in fire-vulnerable plant species and habitats have also been observed, and contemporary fire regimes are directly implicated as a key driver of these changes.
- Experimentally imposed fire treatments (often involving relatively intense fires) do not necessarily equate with ambient (i.e. non-experimentally imposed) fire regimes. This finding has significant implications in predicting the effects of fire regimes on species responses and biomass change.
- Compared with extensive late dry season wildfire conditions prevalent across much of the northern savannas, effectively managed fire regimes have significant benefits for biodiversity conservation (e.g. for fire-vulnerable plant and animal taxa), greenhouse gas emission abatement and carbon storage outcomes.
- Extensive cross-cultural research demonstrates that customary Aboriginal landscape-scale fire management approaches are generally appropriate for achieving desired conservation outcomes in savanna settings.

Key management recommendations

- Fire management of fire-prone savanna systems needs to be strategically prescribed at landscape scales and implemented progressively from early in the dry season as the country dries out (i.e. as fuels cure). This is to reinforce natural barriers (e.g. watercourses) and built barriers (tracks and roads) in order to reduce risk of very extensive late season wildfires.
- Fire management needs to be patchy, ideally with: (1) burnt patches at hectare (to at most tens of hectares) scales; and (2) fire-free intervals of at least 4–5 years. Such scales are required particularly for conservation of relatively immobile fauna with small home ranges and longer-maturing plants with limited dispersal capabilities that rely on seed alone to regenerate. Currently, fire frequencies, and the large size of most savanna fires, typically greatly exceed these requirements.
- There is no single fire regime that caters for the requirements of all species and habitats. Fire management for biodiversity conservation outcomes must be undertaken as an adaptive management process informed by long-term monitoring.
- Effective fire management is also reliant on complementary programs minimising the compounding effects of flammable invasive grass species and the post-fire grazing pressure from introduced domestic livestock.
- Given the increasing inability of conservation managers to deliver effective fire management due to resourcing constraints, there is an evident need to promote the development of supportive environmental services arrangements (e.g. commercial savanna burning offsets projects) in partnership with other regional landscape managers.

Desert complex ecosystems

Chapter authors: Christopher Dickman, Glenda Wardle, Jeff Foulkes and Nicki de Preu

Ecosystem overview

The desert complex environments are among Australia's most iconic and include vast undulating plains, stony deserts, rocky upland deserts and the red sand dune seas of the Simpson, Great Sandy, Great Victoria and Gibson Deserts. These vast areas contain richer communities of lizards, small mammals and some insects than any other of the world's deserts. In the book, these complex environments are defined as areas that are dominated by hummock grassland. These generally occur more than 200–500 km inland from the coast and lie entirely within the boundaries of the arid zone – an area covering approximately 65% of Australia, characterised by variable, low rainfall (150–350 mm a year) and high rates of evapotranspiration that ensure water is usually a limiting factor.

FIG. 8. (a) Gently undulating gibber plains encroach into desert complex environments in many areas. They support very sparse above-ground vegetation during droughts but provide habitat for distinctive fauna such as this Eyrean Earless Dragon (photo by Aaron Greenville)*; (b) Flinders Ranges National Park, South Australia. This vista shows the dominance of Flinders Ranges Spinifex in the background landscape, with Rock Grass Trees in the foreground* (photo by Damien Pearce)

The research

In the book, the results from two core long-term studies are discussed. These networks of desert plots allow scientists to monitor changes in the presence of different plants and animals over time, confirm the habitats, foods and other resources that they need to persist, and identify places in the landscape that serve as refugia during times of drought. The monitoring also enables researchers to quantify the effects of wildfires, introduced predators and overgrazing, and provide insights about how the deserts might best be managed. To date, this research shows that plants and animals typically go through 'boom' and 'bust' cycles in their numbers and distributions and that these spectacular events are driven primarily by heavy rainfall events and intervening droughts.

Study name	Data collected	Start year	Current status
Desert Ecology Plot Network/Simpson Desert Study	Animals and vegetation structure	1990	Ongoing
Bounceback/Flinders Ranges Study	Animals and vegetation structure	1994[1] 2000[2]	Ongoing Finished 2004

[1] Kangaroo monitoring, [2] bush bird monitoring.

Key discoveries

- Heavy rainfall stimulates pulses of productivity in desert complex environments, but must exceed certain thresholds for some species to respond. For example, annual rainfall of 400 mm usually triggers population increases in small native rodents such as the Fat-tailed Pseudantechinus.
- Analysis of plot data over 22 years has shown that weeds and pest species such as Red Foxes and feral cats invade desert complex environments after heavy rain and place many native species at increased risk of local extinction for 2–3 years after the rain event.
- During droughts, when desert complex environments are most stressed, long-term monitoring has been crucial in tracking the movements and distribution of native species so that their drought-refugia can be identified. Some oases, such as riverine strips and swamps, are obvious, but more subtle refugia that have been identified include small patches of woodland on heavy clay soils, individual trees or shrubs, and piles of rocks that provide buffered climates when conditions are very dry.
- Rabbits cause damage to the vegetation of desert complex environments, but their populations often decline during dry conditions or due to disease. Analysis of plot data over 17 years has shown that overabundant kangaroos also damage native vegetation and must be carefully managed to ensure the recovery of vegetation communities.

Key management recommendations

Long-term strategic management is needed to maintain biodiversity in desert complex environments. To achieve this it is recommended that:

- Priority sites of critical habitat and refugia should be identified and intensively managed for all the factors that threaten biodiversity. The control of introduced predators (Red Foxes and feral cats) and of grazing pressure by feral pests (e.g. camels, pigs and goats) also should be coordinated by integrating best practice management throughout the landscape, not just on reserves.
- Water resources should be conserved by minimising damage to natural springs and soaks and by restricting proposals to dam or divert dryland rivers.
- Both exotic and native species should be managed to retain biodiversity.
- Conservation schemes should be encouraged on private land. These should include programs that prevent overgrazing and encourage joint management with traditional owners.
- It is imperative to maintain funding schemes that promote successful outcomes for land use and conservation.

Chenopod and acacia shrublands

Chapter authors: Jeff Foulkes, Nicki de Preu, Russell Sinclair, Nicole Thurgate, Ben Sparrow and Andrew White

Ecosystem overview

Chenopod and acacia shrublands occur within the broad deserts and therefore have many affinities with the desert complex (as described in the previous section) and tussock grasslands (described in the following section). These shrublands are a significant feature of arid Australia and include the vast karst plains of the Nullarbor Plain, stony 'gibber' deserts, rocky uplands, and sand plain and dune fields of the sandy deserts. There have been substantial losses in this ecosystem to date – since European settlement, around 50% of mammals have been lost and there has also been a reduction in the number of many birds and reptiles. Additionally, some plant species have become extinct and many communities are undergoing severe modification.

FIG. 9. *(a) Long-term monitoring has found the Long-Tailed Dunnart to be relatively common at Lorna Glen Station following the removal of threats* (photo by Mark Cowan); *(b) one of the many bluebush plants found in chenopod shrublands; here the contrast between the distinctive blue 'leaves' and the flowers is shown* (photo by Nicki de Preu)

The research

In the book, two long-term core studies in South Australia are used to examine environmental trends. Other monitoring programs are also referred to in feature boxes. The Koonamore-based study documents the recovery of arid zone vegetation following the removal of grazing by sheep and rabbits. The second study demonstrates changes in small vertebrate animal populations in response to reduced rabbit numbers and grazing by domestic livestock. From both studies, it is clear that rainfall is the most important factor influencing changes in the number of plants and animals.

Study name	Data collected	Start year	Current status
TGB Osborn Vegetation Reserve, Koonamore	Plants and vegetation structure	1926	Ongoing
Bounceback Central and Northern Flinders Small Vertebrate Monitoring	Animals	1997	Ongoing

Key discoveries

- Analysis of long-term rainfall data from stations in chenopod and acacia shrubland environments revealed rainfall is highly variable in time, space and intensity. Prior to rainfall data being widely accessible, some of these patterns were not clearly evident.
- Data from Koonamore plots over prolonged periods (>2 years) demonstrate that regeneration in chenopod and acacia-dominated shrublands requires high rainfall. However, responses vary depending on the species.
- Chenopod and acacia shrublands are largely fire sensitive, so changes to fire regimes can have substantial effects on their composition, distribution and extent.
- The Bounceback study demonstrated that populations of small vertebrates continue to persist in areas that have been historically subject to high levels of grazing by domestic livestock and introduced herbivores.
- Much of our ecological knowledge of these systems has been gained from relatively few long-term sites. This is because systematic biodiversity monitoring programs are virtually non-existent in chenopod and acacia shrublands. The emphasis of current monitoring programs relates to how pastoral production influences native vegetation.

Key management recommendations

- Strategically target key refugia and habitats for exotic predator and rabbit eradication, particularly following major rainfall events.
- Promote engagement between researchers and land managers, encourage conservation and stewardship projects on private land, including incentive programs that lower total grazing pressure.
- Promote sustainable use of water resources, minimising impacts on aquifers, surface waters and overland flow.
- Extend funding schemes to continue research that promotes and examines co-existence of viable populations of native plants and animals, and sustainable land use.
- Coordinate targeted management of both exotic herbivores and plants, and native species (e.g. kangaroos) to retain and enhance biodiversity.
- Maintain research activities at locations such as Koonamore and expand the range of long-term biodiversity monitoring activities across the chenopod and acacia shrublands, co-located where possible with pastoral monitoring activities.

Tussock grasslands

Chapter authors: Andrew White, David Orr, Paul Novelly and Gary Bastin

Ecosystem overview

Tussock grasslands are characterised by the dominance of several grasses, generally perennials (i.e. plants that live longer than 2 years), which grow as discrete tussocks rather than a 'lawn'. Dominant grasses are typically bluegrasses, Kangaroo Grass, Mitchell grasses and ribbon grasses. These grasses are palatable to livestock and hence the major land use of this ecosystem is pastoralism, predominantly grazing by cattle and sheep.

Tussock grasslands are widespread across approximately 7% of the Australian continent and through arid, temperate and tropical areas. They occur in all states and territories, with major areas in central and western Queensland and the channel country of southern Queensland. The vegetation structure can range from open grasslands to areas with sparse trees or shrubs, with the inter-tussock areas supporting a wide range of other plants.

FIG. 10. *(a) An example of a tussock grassland, a Mitchell Grass plain on the Barkly Tableland, Northern Territory, during the dry season. Mitchell Grass plants form discrete tussocks, which is the defining feature of tussock grasslands* (photo by Suzanne Shearer, Australian Agricultural Co.); *(b) populations of the Long-Tailed Planigale can reach high densities in tussock grasslands. The species persists well with pastoral use, but population densities decline with heavy grazing pressure* (photo by Kieran Palmer)

The research

Unlike the other ecosystems, the core studies presented in tussock grasslands do not contain data from biodiversity research or monitoring. Instead, they describe data from long-term pastoral monitoring activities. This is because there is no long-term biodiversity monitoring in tussock grasslands. Some biodiversity surveys have occurred in limited areas, but with little or no follow-up work. The pastoral monitoring indicates that climate is the key driver of tussock grasslands and that contemporary pastoral management is sustainable; that is, tussock grass species have been retained with grazing at moderate stocking rates, even over extended periods. However, current monitoring activities are too infrequent and dispersed to provide reliable information on ecosystem drivers and provide no data on native animals, or on native vegetation that is not important for livestock grazing.

Study name	Data collected	Start year	Current status
Astrebla grasslands Queensland: Toorak Research Station	Plants and vegetation structure	1984	Finished (2010)
Tussock grasses: WARMS Kimberley plots	Plants and vegetation structure	1994	Ongoing
Kidman Springs Exclosures: Tussock grass and tree/shrub dynamics in the Victoria River District	Plants and vegetation structure	1973	Ongoing

Key discoveries

- Outcomes from the three core studies have each confirmed that climate is the key driver of plant species distribution and dynamics of tussock grasslands.
- Current grazing practices sustain key pastoral grasses – the long-term monitoring in the Kimberley, Victorian River District and Mitchell Grass Downs (in western Queensland) illustrates that pastorally desirable tussock grasses are retained after decades of grazing.
- Although there is no biodiversity monitoring for tussock grasslands, extensive pastoral monitoring programs assess vegetation and (to a minor extent) soils and limited one-off biodiversity (fauna and flora) surveys have been undertaken. These provide valuable data on the tussock grasslands, but are inadequate to reliably assess biodiversity trends.

Key management recommendations

- Recognise the importance of biodiversity and the sizeable gaps in knowledge and understanding of tussock grass ecosystems. Land users, natural resource management groups, researchers, governments and the public should collaborate to develop regional/bioregional biodiversity management plans that coordinate widespread responses to deal with research, monitoring and management requirements.
- Ensure adequate areas exist that are managed to enhance numbers of threatened species and the condition of particular habitats. This may require the formation of additional reserves or the establishment of on-property conservation areas and management agreements.
- An initial remedial action (from the biodiversity management plans recommended above) should be to provide logistical and operational support to implement targeted and coordinated threat-abatement programs for the control of feral animals and invasive plants.

Tall eucalypt forests

Chapter authors: Sam Wood, David Bowman, Lynda Prior, David Lindenmayer, Tim Wardlaw and Richard Robinson

Ecosystem overview

Tall eucalypt forests are iconic ecosystems renowned for their great height and the rapid growth rates of the trees that grow within them. They contain some of the largest trees in the world – including the world's tallest flowering plants – and are highly valued for their biodiversity, timber production and social values. In the past, these values have been threatened by land clearing for agriculture, but now the most threatening processes come from unsustainable timber harvesting and changes in the fire regimes that characterise these forests. However, these forests also undergo periodic attack from diseases and pests and may be vulnerable to changes in climate through increased temperature, decreased rainfall and the effect of the increased occurrence of extreme weather on fire regimes.

Tall eucalypt forests have a relatively narrow range, comprising only 4% of forest areas in Australia or about 0.75% of the continent. Tall eucalypt forest communities are distributed across Australia in a discontinuous arc of high rainfall areas and comprise four broad groups including: (1) northern Queensland; (2) northern NSW and southern Queensland; (3) Victoria and Tasmania; and (4) the south-west of Western Australia.

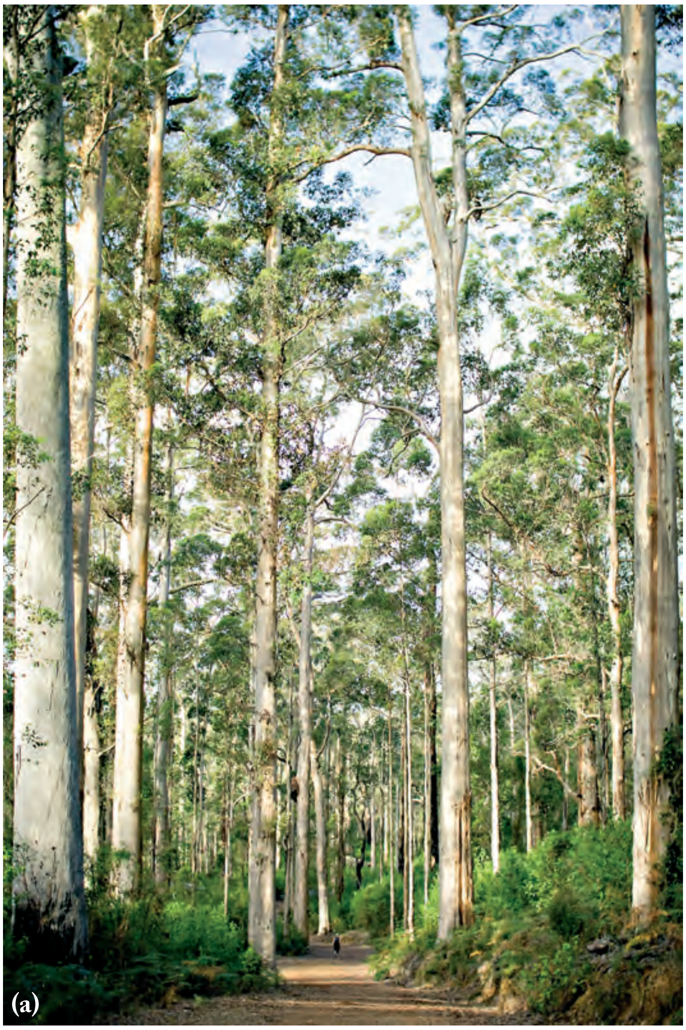

FIG. 11. *(a) Mature stand of Karri tall forest with wet sclerophyll understorey, Pemberton region, Western Australia* (photo by Farhan Bokhari); *(b) Greater Glider – a species that is declining rapidly throughout the mainland Mountain Ash forests of the Central Highlands of Victoria* (photo by Esther Beaton)

The research

Tall eucalypt forests have been the focus of many research initiatives largely aimed at understanding disturbance ecology and the impacts of timber harvesting on a range of forest values. The four core studies presented in the book reveal trends in fungi, birds, arboreal marsupials, vascular plants, invertebrates and tree growth in tall eucalypt forests, and the way that various processes influence these trends at site, landscape, regional and continental scales. Despite well over 25 years of dedicated research in these systems, the trends identified represent a preliminary understanding of environmental change in these ecosystems that operate on temporal scales of months to centuries.

Study name	Data collected	Start year	Current status
Continental Permanent Inventory Plots[1]	Plants and vegetation structure	1960s	Ongoing
Victorian Tall Eucalypt Forest Plot Network	Plants, animals and vegetation structure	1983	Ongoing
Tasmanian Warra Plot Network	Plants, animals and vegetation structure	1995	Ongoing
Western Australian Karri Forest Plot Network	Plants, animals and vegetation structure	1984/1982/1997	Ongoing

[1] This refers to the tall eucalypt sub-set of this more extensive study

Key discoveries

- An analysis of tree growth from over 1000 permanent inventory plots distributed across Australia has indicated that tree growth in tall eucalypt forests is related to climatic variables. Predictive models based on these relationships infer a decrease in tree growth under various climate change scenarios.
- Plot networks in the Mountain Ash and Alpine Ash forests of Victoria revealed highly idiosyncratic temporal changes in populations of arboreal marsupials and birds, particularly after the 2009 wildfires.
- Long-term monitoring of birds, fungi, beetles and vascular plants in harvested and unharvested forest plots in southern Tasmania and south-western Australia showed that the recolonisation of harvested areas by different groups of flora and fauna varies markedly and depends, in part, on retained forest elements within the post-harvest area (e.g. habitat trees, logs and patches of intact forest).

Key management recommendations

- Use predictive models of tree growth to inform management that attempts to balance economic (e.g. timber production) and environmental (e.g. carbon storage, water yield) values of the forest estate. It is crucial to maintain networks of long-term forest monitoring plots to provide data that will improve the understanding of relationships between climate and tree growth within these predictive models.
- To effectively manage the conservation values of tall eucalypt forests, it is critical to protect hollow-bearing trees. This will, in part, allow populations of cavity-dependent animals, such as arboreal marsupials and birds, to persist.
- Adopt new harvesting practices based on a robust understanding of the ecology of the forest being managed. Variable retention harvesting, which seeks to maintain large patches of intact forest within harvested areas, appears to be the optimal form of harvesting for ensuring the persistence of mature forest biodiversity in the tall Messmate forests of Tasmania.

Box 7. Overall, Australia has a poor environmental management record

Australia supports an extraordinary range of environments and many of our plants and animals are unique to this country. These environments and the nation's biodiversity are discussed in the book, as is Australia's environmental management record relative to other nations. The environmental metrics examined were CO_2 emissions, energy use, fossil fuel energy consumption, total number of threatened species and total forest lost between 1990 and 2010. Unfortunately Australia is frequently among the worst-performing countries globally when comparing environmental metrics.

The book highlights how poorly we manage the natural resources of Australia and how heavily Australian society consumes natural resources and pollutes the environment. For example, Australia is the only country in the world to have lost more forest in the last decade (2000–2010) than the previous one (1990–2000). Although data reporting standards for the Global Forest Resources Assessment (see recommended web links) can be easily criticised (due to poor self-reporting standards in some countries), what is clear from this report is that Australia joins Brazilian Amazonia and South-East Asia as a region losing forests at a very high rate.

Australia has a well-documented history of neglecting the environment. Despite ongoing investment and effort, Australia has failed to reduce the rate and scale of environmental degradation. The reasons for these ongoing problems are complex and not well understood. However, two contributing factors are: (1) a lack of appropriately designed programs that allow critical examination of the on-ground effectiveness of management actions; and (2) a lack of monitoring to gather the necessary data to inform management and policy adaptation. Improving these two aspects will provide better information from which Australians can make important decisions.

Box 8. There are cultural barriers to effective environmental management in Australia

To inform the management of Australia's natural and cultural resources, conservation science needs to be better integrated into environmental policy. However, there are many challenges to achieving this. In the book, we explore some of the key cultural drivers and challenges that influence the way that we, as a nation, engage with the environment and how we reconcile environmental investments against social and economic aspirations. The main cultural drivers examined are the culture of science itself, the influence of different land use industries and the cultures inherent to education, Indigenous Australia, economics and policy.

The challenge for government is to set priorities and develop coherent policies that respect the diversity of interests in the environment and natural resources held within our society while also maintaining environmental values for future generations. This will require collaboration between ecologists, social scientists, government, industry stakeholders and the community to produce a long-term vision that not only facilitates ecological sustainability but also facilitates inclusive and adaptive approaches to land use and management.

Box 9. The known and common threats

As highlighted in Box 3, the dynamic interactions between organisms and their environment can fail if threats erode ecosystem function. In the book, the authors discuss threats to the ecosystems they have been studying. In the final chapter of the book, threats and key ecosystem drivers are summarised. In brief, the threats identified and discussed are:

- *Changes in the frequency and severity of fire.* A key example is in the tropical savannas where small mammal declines have been linked to inappropriate fire management, which has altered the frequency and severity of fire in the system.
- *Grazing by domestic livestock and over-abundant numbers of native animals*. A key example is in the temperate eucalypt woodlands where grazing pressure from domestic livestock and kangaroos is a key threat to these woodlands. As grazing pressure increases, native plant diversity is reduced and exotic plant species cover increases. Limited natural regeneration, soil compaction, and altered habitat lead to the decline of animal populations.
- *Clearing and fragmentation of remaining native vegetation*. The ongoing clearing of native vegetation in Australia is a threat to most ecosystems. According to the 2011 State of the Environment Report, about 1 million hectares of native vegetation is cleared annually in Australia in spite of the recognition that habitat loss is one of the primary drivers of extinction and decline.

- *Plant disease*. A key example is root-rot disease, caused by a water mould known as Cinnamon Fungus. At present, this is the most acute threatening processes affecting heathland biodiversity. This is the threat driving the most rapid and seemingly irreversible losses and the threat most lacking suitable options for management responses. If this situation continues, Australian heathlands will face a significant loss of plant diversity and dependent animals.
- *An increase in nutrients within an ecosystem*. Nutrients can be added to ecosystems in many ways. Key examples are from domestic livestock, or aerial applications of crop fertilisers, herbicides, fire retardants and disease-treatment chemicals. These all result in incidental enrichment of plant nutrients such as phosphorus. This can produce toxicity symptoms in native vegetation, weed invasion and changes in the activity of some animals (especially insects).
- *The invasion of exotic plants and animals*. This is a key threat to all Australian ecosystems. For example, in the deserts, weeds such as Buffel Grass and pests such as camels, feral pigs, rabbits, Red Foxes and feral cats depress populations of native plants and animals, and increase their vulnerability to extinction. The factors that lead to invasions can be complicated and strategically managing this threat is very difficult. Weeds and pest animals remain a key priority for environmental management and is under-resourced.
- *The disturbance of soil*. Soil disturbance and loss of the productive biological soil crusts seriously threaten the functioning of many Australian ecosystems. A key direct example is cultivation, but most disturbances occur indirectly through fire, flood, compaction and erosion by domestic livestock and exotic hooved animals, and added nutrients from livestock and fertilisers. Intact soil crusts comprising cyanobacteria, lichens and mosses decrease soil erosion and contribute to nutrient cycling, but crusts rapidly lose their functional capability if disturbed. Disturbance to crusts also changes flows of surface water and lowers resistance to wind erosion.
- *Increased dryland salinity*. Dryland salinity refers to the dissolved salt content in water or soil. Increased salinity is a major ecological problem in Australia. Farming practices have resulted in rising groundwater levels, which, in many areas, have brought salt to the root zone. At a minimum, the cover of native vegetation needs to be maintained and, preferably, strategically enhanced, to help manage the threat of salinity.
- *Tourism*. Tourism can be a threat because pests and diseases can unwittingly be introduced. Tourism infrastructure also can result in habitat destruction and fragmentation. A key example is root-rot disease in the Stirling Range of south-western Australia. The disease was introduced onto the mountain peaks by walkers unwittingly transporting infected soil. These spot infestations have subsequently spread and resulted in significant losses in biodiversity.
- *The removal of dingoes is a threat in arid environments and potentially other ecosystems*. Dingoes primarily evict or kill Red Foxes and feral cats and thereby provide indirect benefits to many species of small and medium-sized animals in regions where dingoes are allowed to persist. Opposition from livestock producers and their advocates will need to be addressed before the conservation benefits of the Dingo can be more fully realised.
- *Mining, exploration and bio-prospecting*. Although of financial benefit to Australia, these activities have destructive environmental impacts. In addition to better management of current and new mines, more needs to be done to restore areas that were previously mined. A key example is heathland restoration of sandmined areas, which has been successful in promoting the re-establishment of some ground mammals. However, restoration of the native plant communities has been limited.
- *Altered hydrological regimes*. Hydrological processes are a key component of ecosystem function: they determine water balances, rainfall-runoff relationships, water availability, occurrence of floods and feedback mechanisms between the Earth's surface and the climate. Land-use practices that alter hydrology can have immediate economic and social benefits, but conversely they have significant long-term impacts on biodiversity.
- *Climate change*. The variable climate, especially climatic extremes of flooding and drought, is a dominant driver in many ecosystems. It is widely acknowledged that the environmental challenges faced in Australia (and around the world) will be exacerbated by an increasingly variable climate in coming decades, with more climate extremes.

These threats are not mutually exclusive and can have complex interactions that are difficult to identify and measure. The impacts of management can also be hard to determine. Long-term research, in combination with adaptive long-term management strategies, is needed to tackle these threats.

The social imperative

To be ecologically sustainable, it is imperative for our society to learn and adapt. Adaptive learning and management are words that are easy and convenient to say, but applying the principles at meaningful scales is very difficult because of the short-term basis on which modern complex societies are governed.

To manage Australian natural resources and conserve biodiversity adequately, we need to understand the condition of the environment and how it is changing and then, most importantly, what adaptations (if any) should be made. In Australia, we have some of the most eminent and well-regarded environmental scientists in the world. These scientists have a wealth of knowledge that governments need to better harness to tackle current and looming environmental challenges. The need is evident because, to date, the social response to environmental degradation and the predicted and communicated consequences of this degradation have arguably been heavily politicised, tentative and essentially inadequate. It is difficult to know how best to grapple with this problem, but one significant area for improvement is the transfer of knowledge from scientists to policy and on-ground management. We are not implying that environmental scientists have all the answers or solutions, but they do possess an understanding of the environment and its critical dependencies.

This extensive knowledge is, in part, demonstrated in the book, which is the first compilation of findings of long-term ecological research across multiple ecosystems in Australia. The fascinating overviews and insights provided demonstrate that these networks of monitoring sites are a key part of Australia's environmental research infrastructure. It is critical that this basic infrastructure is maintained to allow Australians to learn more about their environment. But this knowledge must be met by better policy and on-ground environmental management.

It is time to act with the urgency, scale and intelligence that is needed to deal with our environmental challenges. A good place to start is managing the known threats (see Box 9) and by formulating management strategies informed by the research and specific ecosystem recommendations in this handbook. To achieve this, we need a long-term systematic approach to the integration of science into natural resource management.

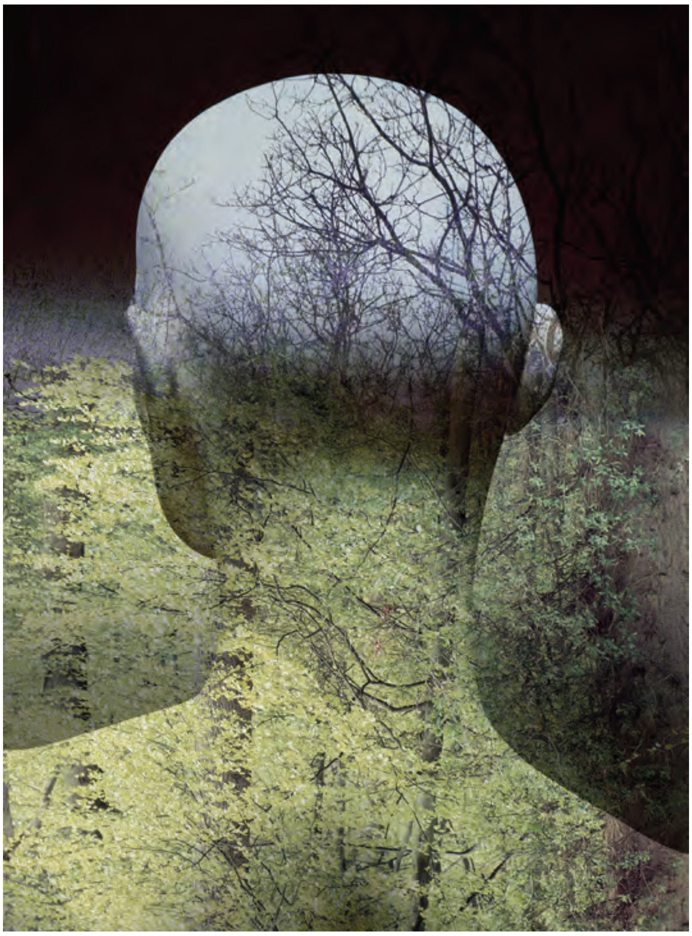

FIG. 12. *Ecology Man, a striking image which symbolises an intimate balance between intelligence and knowledge, and a connectedness to nature – both are needed to achieve sustainability* (photo: Sam Haskins © All Rights, The Sam Haskins Estate 2013)

Recommended reading

1. 'The book' – Lindenmayer D, Burns E, Thurgate N, Lowe A (Eds) (2014) 'Biodiversity and Environmental Change: Monitoring, Challenges and Direction'. (CSIRO Publishing: Melbourne.)
2. Christoff P (Ed.) (2014) 'Four Degrees of Global Warming: Australia in a Hot World'. (Earthscan/Routledge: Oxford, New York.)
3. Glikson AY (2014) 'Evolution of the Atmosphere, Fire and the Anthropocene Climate Event Horizon'. (Springer: Dordrecht.)
4. Kingsford RT, Watson JEM, Lundquist CJ, Venter O, Hughes L, Johnston EL, *et al*. (2009) Major conservation policy issues for biodiversity in Oceania. *Conservation Biology* **23**, 834–840.
5. Lindenmayer D (2007) 'On Borrowed Time: Australia's Environmental Crisis and What We Must Do About It'. (Penguin: Melbourne.)
6. Munro S (2012) 'Rich Land, Wasteland: How Coal Is Killing Australia'. (Exisle Publishing and Pan Macmillan Australia: Sydney)
7. Secretariat of the Convention on Biological Diversity (2010) 'Global Biodiversity Outlook 3'. (SCBD: Montréal.)
8. State of the Environment 2011 Committee (2011) 'Australia State of the Environment 2011. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities'. (DSEWPAC: Canberra.)
9. Tainter JA (2003) 'The Collapse of Complex Societies'. (Cambridge University Press: Cambridge, UK)

Recommended web links

1. Long Term Ecological Research Network, <http://tern.org.au/ltern>
2. The Conversation, <http://theconversation.edu.au>
3. Halt and Reflect: an open letter from scholars regarding global sustainability, <http://haltandreflect.wordpress.com/2012/10/24/openletter/#comment-205>
4. Global Forest Resources Assessment 2010 data, <http://www.fao.org/forestry/fra/fra2010/en/>
5. The implications of climate change for Australia's biodiversity conservation and protected areas website, <http://csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/adapt-national-reserve-system.aspx>

FIG. 13. *Savanna woodland as seen from a waterhole at the top of a waterfall near one of the research plots in the Three Parks Savanna Fire-Effects Plot Network in Kakadu National Park* (photo by Emma Burns)