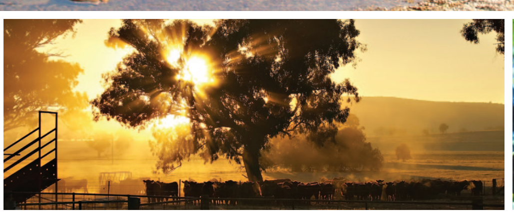
SCIENCE AND SOLUTIONS FOR AUSTRALIA

BIODIVERSITY



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CSIRO

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Foreword

Megan Clark, CSIRO Chief Executive and
Andrew Johnson, Group Executive – Environment, CSIRO

Australians have stewardship of a beautiful, diverse and unique environment. We have long had a sense that the biodiversity of this country is special. We use unique Australian species such as kangaroos and emus in our coat of arms, as commercial emblems, and to identify ourselves at international sporting events. Yet, despite our sense of its importance as part of our national identity, in many parts of our country biodiversity is in trouble.

This book is not just about quantifying the challenge. It is also about identifying practical solutions in response to change in the Australian landscape. Like their colleagues in the companion volumes, *Climate Change* and *Water*, the authors of this book have sought to provide a bridge from the scientific literature to the wider Australian community, while providing the depth of science that this complex issue demands.

In the chapters that follow, CSIRO's leading biodiversity scientists describe the ancient origins and unique features of Australia's species, as well as the current status of our biodiversity on land and in rivers, lakes and the sea. They also outline tools for management and planning, including for Australia's protected area system. The book does not shy away from the problems inherent in translating such a broad canvas of values into pragmatic actions.

One of the unique aspects of Australia's flora and fauna is its interaction with the world's oldest continuous culture, and therefore we have dedicated a chapter to Indigenous perspectives on biodiversity. The book also looks at how Australia's biodiversity interacts with agriculture, the resources sector, cities, and our changing global environment. Importantly, it also shows that biodiversity is in the eye of the beholder: for some it is our life-support system; for others it is a resource to be used; for yet others it is a precious cultural symbol.

Given the economic, ecological and social importance of biodiversity to our nation, CSIRO has been conducting research into Australia's biodiversity for nearly 90 years. CSIRO cannot do its important work without the support of our collaborators and partners. These include Australian and international universities, industry groups, research organisations, governments at all levels and, most importantly, the Australian community.

As Australia's national science agency, CSIRO is committed to providing trusted advice on the major risks and opportunities that our nation faces. We commend to you this synthesis of the latest scientific knowledge on Australia's biodiversity, and on the challenges and prospects for its management in the future.

Contents

Acknowledgements

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Much of the science referred to in the book comes from biodiversity projects of CSIRO and its collaborators, and we would like to thank our many colleagues (too numerous to mention) who provided valuable contributions that strengthened the book.

We would also like to acknowledge the assistance provided by AnneMarie White, Chris McKay, Carl Davies, Andrea Wild, Rebecca Blackburn and CSIRO Publishing for sourcing and producing the images and figures featured throughout the book.

Development of the book was managed by Fiona Brown and Larissa Cordner.

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What is biodiversity, and why is it important?

Steve Morton and Rosemary Hill

Key messages

- Biodiversity is the term used to encompass the variety of all living organisms on Earth, including their genetic diversity, species diversity and the diversity of marine, terrestrial and aquatic ecosystems, together with their associated evolutionary and ecological processes.
- Biodiversity makes human life on Earth possible yet it goes beyond mere measurable scientific facts; understanding biodiversity highlights the benefits of the natural world, many of which are at risk due to the pressures of human resource-use.
- Biodiversity is a human construct reflecting various values – economics, ecological life-support, recreation, culture and science – placed upon it according to perceived benefits and risks.
- This book focuses on options for improving the management of Australia's biodiversity in response to such societal values.

WHAT IS BIODIVERSITY?

A writhing mass of Murray crays is revealed as the drum-net emerges pull by pull from the river, the greenish water draining in pulses from its mesh. The boy watches with keen anticipation as his father strains at a length of fencing wire attached to the net. There are such numbers of crayfish that they crawl in confusion over each other and around the sodden sheep's head that acts as bait. His father unlatches the door of the net and carefully extracts the animals, avoiding harm to his fingers by grasping the body behind the dangerous fore-claws. If eggs of deep crimson are found on the under-tail of a female, she is tossed back into the water, as are young individuals. The boy helps his father carry the wriggling hessian bag containing the catch a hundred metres or so to the homestead. They walk in the shade of the stately, heavy-limbed river red-gums that line the stream, the foliage glowing green and bronze in the late afternoon sun. The boy could hardly be happier.

The Murray River and its river red-gums, Eucalyptus camaldulensis. *Photo: Matt Colloff, CSIRO.*

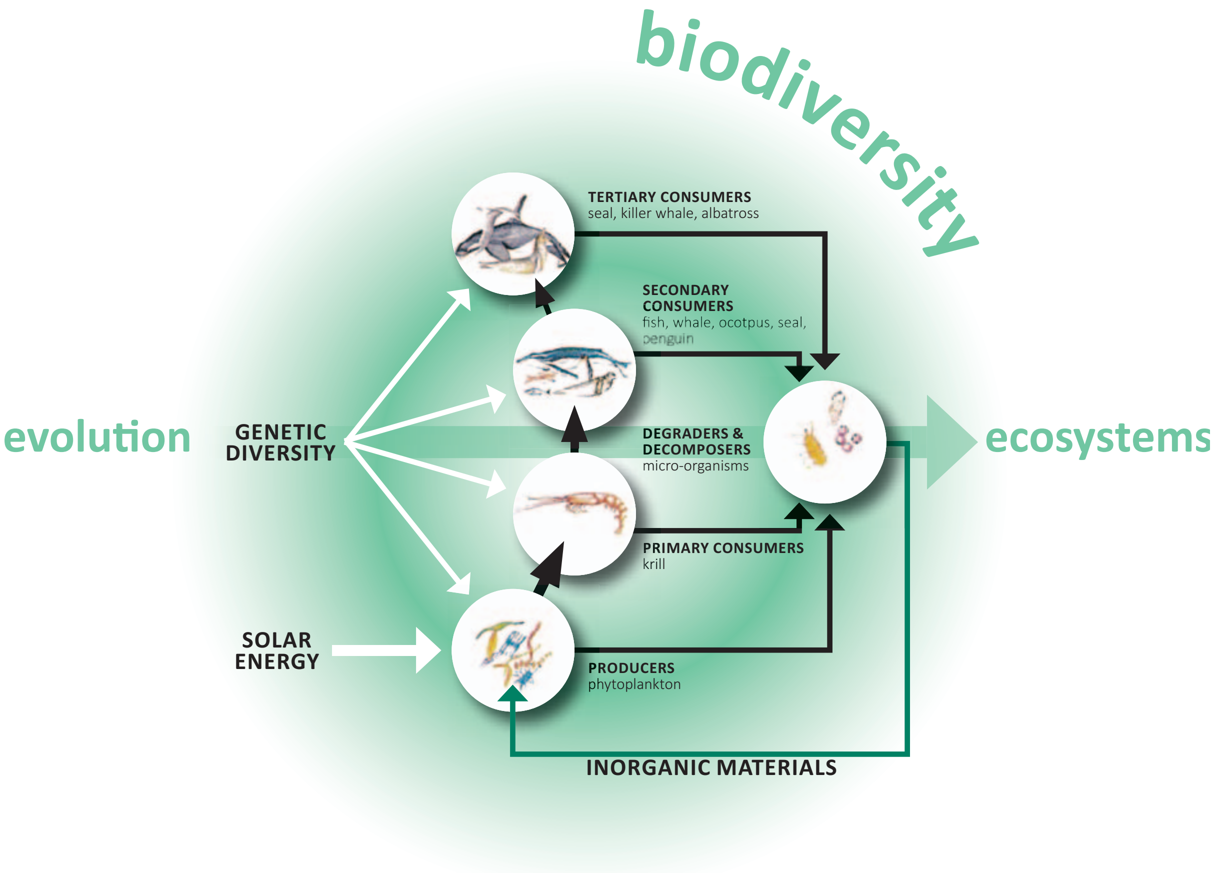
In the laundry the copper is quickly lit and, as soon as its water is boiling, the crays are dropped in to cook. Only a short time is required before they can be lifted out, their original muddy green colours turned to a rosy blush. Father and son sit on the verandah while breaking up the crays and placing the chunky flesh from the fore-claws and tails into a bowl for the family's evening meal. They suck the juicy slivers of meat from the slim hind-claws and scoop out and eat the fatty deposits lining the carapaces. The flavours are deliciously sweet and subtle, a delicacy of taste never to be bettered in the boy's subsequent life. Now he is at a peak of delight, deeply at home in an Australian paradise.

The Murray crayfish, Euastacus armatus*. Photo: Rob McCormack.*

Most of us hold on to some vision of an idyllic, productive or beautiful environment, often imbibed unconsciously in childhood and youth. The man grown from the boy – he is in fact one of the present authors – still admires most of all the Riverina plains country with its splendid river red-gums. Each of us has our own vision, though, not necessarily shared with others. We form a sense of the environmental values of our own particular place, not only as we come to maturity but throughout our lives. These values are at the heart of the concept of biodiversity, a notion that is only partly about science because it is based also in emotional experience and culture. First and foremost, appreciation of biodiversity springs directly from human interaction with the natural world. Often these experiences involve immediate use of the environment, such as working on the land or harvesting its bounty (especially its Murray crays!). Frequently, too, they stem from a simple enjoyment of the natural world through beach-going or bushwalking. Whatever the details of the individual human experience, the idea of biodiversity cannot be fully understood without the recognition of its roots in a perception of environmental values.

Biodiversity does encompass a significant component of scientific inquiry, of course. Scientists define biodiversity as the variety of all living organisms on Earth and at all levels of organisation (Figure 1.1). It incorporates living things from all parts of the globe, including land, sea and fresh waters. It constitutes *all* forms of life – bacteria, viruses, plants, fungi, invertebrate animals, animals with backbones – and not just the things we can see or prey upon. Biodiversity includes human beings too. Yet the scientific definition of biodiversity includes more than just organisms themselves. Its definition includes the diversity of the genetic material within each species and the diversity of ecosystems that those species make up, as well as the ecological and evolutionary processes that keep them functioning and adapting. Biodiversity is not simply a list of species, therefore. It includes the genetic and functional operations that keep the living world working, so emphasising inter-dependence of the elements of nature.

Scientists are striving to describe and measure the full variety of life, a massive undertaking when we consider the estimated nine million species on Earth, their genetic diversity, and the vast variety of ecosystems that they make up.[1] What is more, science aims not only to understand the evolution of this kaleidoscope of life but also the ebb and flow of biodiversity through time



▲ ***Figure 1.1***: *Biodiversity is the web of life. This pictorial representation begins on the left with the evolutionary processes giving rise to the genetic diversity of living organisms, showing the organisation of the species carrying genetic diversity into food chains of producers (driven by energy from the sun), consumers and decomposers, and the ecosystems that the organisms make up. The diagram depicts a marine food chain. Redrawn from* Biology: An Australian Focus.[2]

in response to the inevitable natural disturbances and human-induced disturbances.[3] Science is charged with the responsibility of providing us with the knowledge and evidence needed to meet our diverse expectations for the use and conservation of biodiversity.

So it is that biodiversity is both a subject of scientific interest and a fascinating social construction. The term 'biodiversity' emerged in the 1980s from the conservation movement as a means of emphasising the values of the natural world under the pressure of human-induced environmental change and resource use. The concept underpinned the Convention on Biological Diversity in 1992, as well as considerable activity by governments to try to balance the benefits and risks associated with loss of biodiversity. Behind the term is a shared concern about the future of the planet and the accelerating expansion of humanity's effects upon the global environment. Further, the concept refers to more than measurable scientific facts or fears about risks associated with its loss. People throughout the world, many of whom may never use the term 'biodiversity', appreciate plants, animals, landscapes and seascapes for their usefulness and for qualities such as their spiritual significance – and it is because of these values also that biodiversity matters to us as human beings.

VALUES – WHY BIODIVERSITY MATTERS

Values are the lasting beliefs or ideals that will influence a person's attitude and which serve as broad guidelines for that person's behaviour. Values and value systems identifying what is good or bad, desirable or undesirable, are frequently shared by the members of a culture, even when not consciously expressed. Some values can be expressed in monetary terms so as to allow calculation of a common measure of worth. Yet, economic benefit provides only a partial measure of the full worth of things. Understanding biodiversity, and why it matters, is assisted by comprehending the range of distinctive values that individuals and societies may assign to the living world and the ecosystems that it comprises. It is an indication in itself of the complexity of views about biodiversity, and the variety of interactions with it, that at least five separate categories are necessary to cover all possibilities (Figure 1.2). They are described below, noting numerous possibilities for interaction among them.[4]

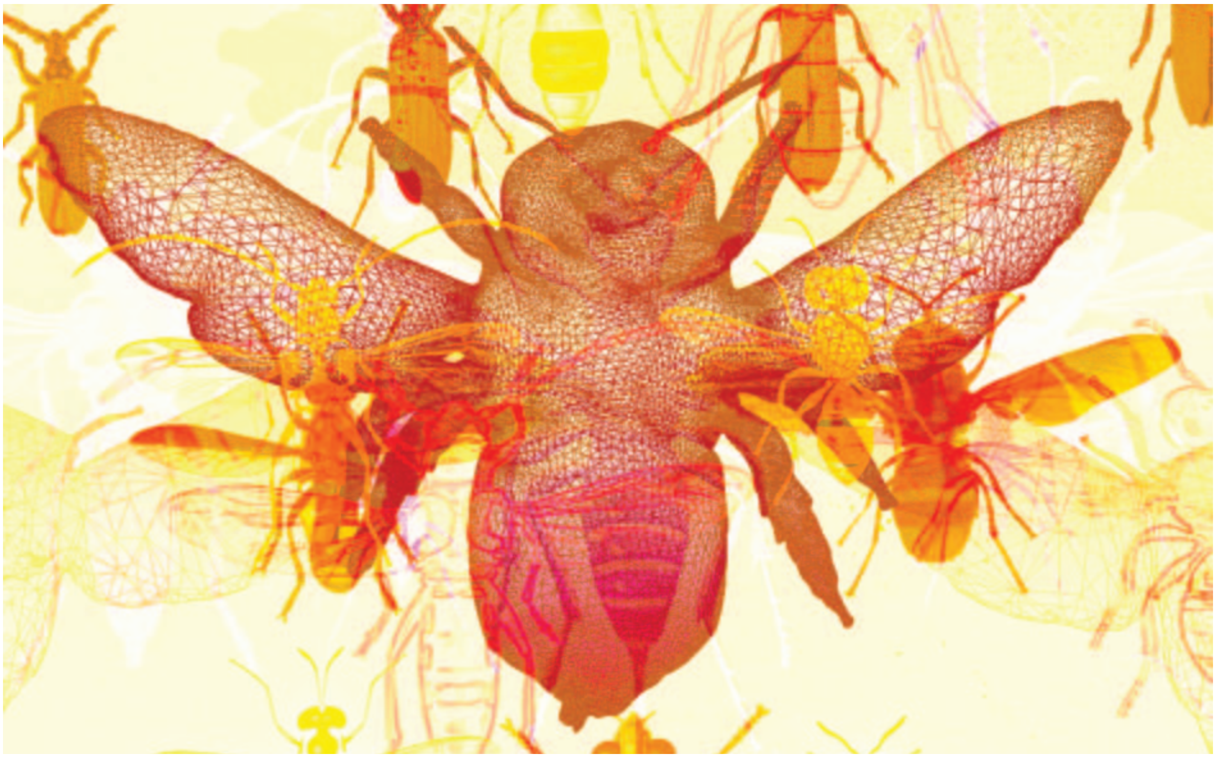
▲ ***Figure 1.2**: The five primary values of biodiversity. Photos clockwise from top: CSIRO; Willem van Aken; Chris McKay; Hans Heysen (Germany; Australia; France, b.1877, d.1968), Summer, 1909, pencil, watercolour on ivory wove paper, 56.5 × 78.4 cm, Art Gallery of New South Wales (AGNSW), purchased 1909, Photo: AGNSW, © C Heysen; David McClenaghan.*

The first category has already been mentioned – *economic*. The natural world provides humans with raw materials for direct consumption and production, and from which to make money. We harvest fish and timber, for example, and make from them food and goods with utilitarian value in the marketplace. This category expresses the material use of nature by humans for direct benefit. These benefits – and the economic value system that lies behind them – are held especially dear by many whose livelihoods bring them close to the natural world, such as farmers, fishers, timber workers, bee-keepers, and so on.

A second value system comprises *ecological life-support*. Biodiversity provides humans with the healthy, functioning ecosystems that make up the Earth, without which our societies could not exist. Nature delivers to us a supply of oxygen, clean water, pollination of plants, pest control, and so on. As understanding and evidence about the interconnectedness of the natural and human worlds has grown over the past century, many have come to believe that protection of the web of life is vital to our own interests, and biodiversity is a convenient expression of that value system. In fact, the concept of 'ecosystem services' – the multitude of resources and processes that are supplied by biodiversity to human beings – grows out of this value. Such a value system is shared by almost all human beings in at least some degree.

The natural world's opportunities for human *recreation* comprise the third set of values. The benefits of rejuvenation for those who hold to these values may be obtained from a tough bushwalk in Tasmania, a relaxed experience of bird-watching in the back paddock, or jogging beside a river in an urban setting. Tourism frequently gains commercial benefit from biodiversity as a result of international perceptions that in Australia these values are unusually prominent. Many Australians from all walks of life respond to them.

Next, biodiversity provides *cultural values* via the expression of identity or through spirituality or an aesthetic appreciation. The celebration in our National Anthem that 'our land abounds in nature's gifts of beauty rich and rare' reflects an attachment to biodiversity that is a widely shared aspect of Australian culture. Virtually every Australian who returns from overseas has

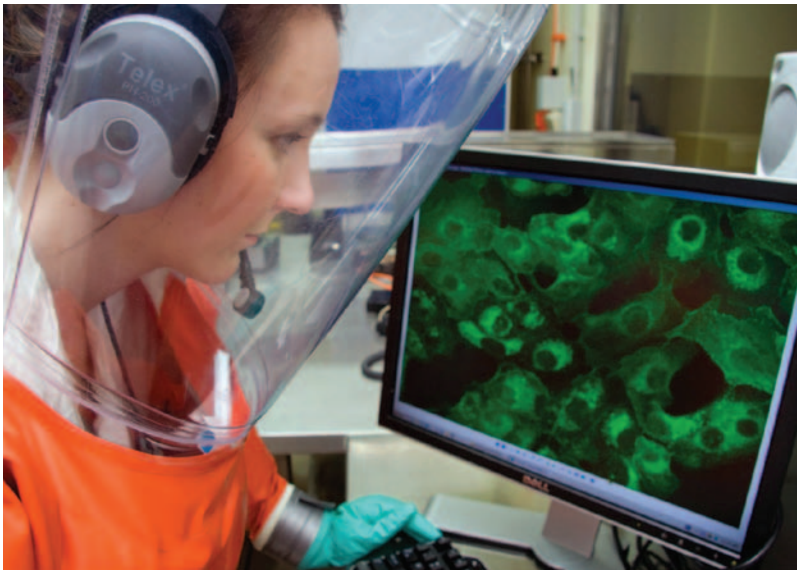


Using reworked high resolution 3D scans of insects to create an eye-catching mosaic, this artwork is an example of the cultural value of biodiversity. Image: Artwork by Eleanor Gates-Stuart, CSIRO; original insect scans by Dr Chuong Nguyen, CSIRO; original insect illustrations by F. Nanninga, CSIRO.

experienced a satisfying re-exposure to the odour of gum leaves. Indigenous peoples in Australia express cultural values especially strongly and in an unusually intimate fashion, through totemic connections to animals and plants that are believed also to be ancestral beings. Spiritual values are a subset of such connections, an opportunity to explore questions about the meaning of the universe through contemplation of biodiversity. The splendour of nature also provides aesthetic values simply through the appreciation of the non-human world. Obviously enough, artists are frequently the major bearers of this value system and, like most nations, we have a long tradition of exhilarating practitioners, such as Hans Heysen, Fred Williams and Emily Kame Kngwarreye. Yet aesthetic values are also appreciated more broadly across society, and often by direct individual absorption in a natural context as well as by reflection in art galleries or in the words of poems and songs. Finally, education makes up another aspect of cultural values, providing the basis for discussion about how to live sustainably on planet Earth.

Fifth is a *scientific value* system, which calls attention to the worth of systematic ecological data in helping us to understand the natural world, its origins, and the place of the human species within it. Scientists are likely to highlight the excitement of uncovering genetic diversity, for example, or cataloguing the strange creatures of the deep-sea trenches, or understanding how vegetation patterns are influenced by fire. While economic benefit may well accrue from scientific understanding, the motivation of the scientific value system is primarily intellectual. All of the authors of the present book share this value system.

Lastly, for completeness there is a *negative value* system, a stance towards biodiversity characterised by fear or hostility. Settler Australians were prone to the expression of such anti-values, which persist today in relation to some animals (an understandable fear of crocodiles or of influenza viruses). Negative views are not confined to Australia, of course, because apprehension about spiders and snakes, for example, is common to many cultures. And it is also true that virtually no one feels compelled to defend the right of the malarial parasite to continued existence, or argues in favour of the Hendra viruses, even though biodiversity encompasses life in *all* of its variety. Negative values are likely to be held in some small part by many people, therefore, although their significance in Australia declined throughout the 20th century and narrowed to specific targets.



This CSIRO scientist studies a fluorescently stained image of cells infected with Hendra virus. Her encapsulated suit reminds us of the deadly nature of some life-forms: not every biodiversity value is regarded as positive. Photo: Frank Filippi, CSIRO.

VALUES – WHY WE WORRY ABOUT BIODIVERSITY

Humans are presently concerned about biodiversity because there is undeniable evidence of significant global and Australian declines. The problem is real, as shown in Chapter 3 of this book. Decline in biodiversity may compromise each of the values outlined above, even though it may not be immediately evident how to measure an impact on any one of them. Scientific progress is being made, though, in understanding likely consequences of declining ecological life-support. We now know the following general principles:[5]

- Biodiversity loss can reduce the efficiency with which ecosystems acquire resources, produce biomass, and decompose it to recycle nutrients.
- Maintenance of biodiversity allows ecosystems both to keep working in the face of ongoing change and to recover functions more readily after a shock.
- The impact of a decline in biodiversity on the ecosystem accelerates as the loss increases.
- Diverse communities may be more productive because species differ in the way they capture energy and nutrients, so leading to a potentially greater collective uptake.
- Loss of diversity at multiple levels within a food chain (e.g. from grasses through grazing animals to their predators) can influence ecosystems more than loss within just one level.
- Effects of extinction range from undetectable (for species having small roles in ecosystem functions) to profound (for those that dominate the working of the ecosystem).

These six findings represent important advances in our understanding of the value of ecological life-support. Nevertheless, science is struggling to translate this growing knowledge into thresholds of concern: at what point in biodiversity decline should humans become worried to the point of taking corrective action, and what aspects of the challenge of managing biodiversity should be addressed first? This book cannot answer all those deep questions, yet it will provide important pointers.

BIODIVERSITY AND HUMAN SOCIETIES

Discussion of value concepts highlights the fact that the linkages between biodiversity and human societies may be as multifaceted as are those within ecosystems. The Millennium Ecosystem Assessment in 2005 was the first global effort to examine links between human wellbeing and biodiversity.[3] The Assessment found benefits to societies from biodiversity in material welfare, security of communities, resilience of local economies, relations among groups in communities, and human health. It also emphasised the term ‘ecosystem services’ under four broad categories: *provisioning*, the production of food, fibre and water; *regulating*, the control of climate and diseases; *supporting*, nutrient cycling and crop pollination; and *cultural*, such as spiritual and recreational benefits (Figure 1.3).

Provisioning Services	
Food:	Ecosystems provide the conditions for growing food such as fish in wild habitats.
Raw materials:	Ecosystems provide materials for construction such as fine timbers.
Fresh water:	Ecosystems provide surface and groundwater.
Medicinal resources:	Many plants are used as traditional medicines and as input for the pharmaceutical industry.
Regulating Services	
Local climate and air quality regulation:	Water and vegetation reduce temperature extremes.
Carbon sequestration and storage:	As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
Moderation of extreme events:	Ecosystems can create buffers against natural hazards such as floods.
Waste-water treatment:	Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.
Erosion prevention:	Vegetation prevents river and foreshore erosion.
Pollination:	Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
Biological control:	Ecosystems are important for regulating pests and vector-borne diseases.
Habitat or Supporting Services	
Habitats for species:	Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
Maintenance of genetic diversity:	Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial species.
Cultural Services	
Recreation and mental and physical health:	The roles of natural landscapes and green space for maintaining mental and physical health are increasingly being recognised.
Tourism:	Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
Aesthetic appreciation and inspiration for culture, art and design:	Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
Spiritual experience and sense of place:	Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

▲ ***Figure 1.3****: The range of services that biodiversity may provide for people, under four broad categories.*[6] *Icons designed by Jan Sasse.*

The Assessment also noted that many people have benefited from the conversion of natural ecosystems to human-dominated farms, towns and cities. It confirmed that the concept of biodiversity stems from dynamic interactions between people and their environment, rather than being something separated from humanity. It is now recognised that every ecosystem on Earth is influenced by such interactions, and there is a growing scientific effort to study biodiversity as a social–ecological system. New models are attempting to integrate human behaviours with ecosystem functions, to incorporate the feedbacks among them, and thereby to explore more effective policies for conservation and utilisation of resources.[7]

A new term has been mooted – 'biocultural diversity' – to highlight the fact that the full diversity of life includes human cultures. Biodiversity and human cultural diversity possess a fascinating overlap, because global 'biodiversity hotspots' (only 2% of land area) also include 70% of the languages on Earth. Environmental complexity and abundance of resources are some of the ideas currently being tested as explanations for the links between high biological and high cultural diversity.[8] In Australia's case, Indigenous Australians see plants and animals as possessing dual ecological and social identities, their systems of law and management aiming at the protection of both cultural and biological diversity.[9] For this reason this book includes a section in Chapter 6 dedicated to Indigenous views of biodiversity. The roles of Indigenous Australians are emphasised also for practical reasons: Indigenous rights and management responsibilities are recognised to varying extents in over half of Australia's landmass through grant or purchase of title, determination of Native Title, Indigenous Land Use Agreements and Indigenous Protected Areas, which now make up 40% of the National Reserve System.[10]

So we return to the way individual members of society discern values in biodiversity and appreciate their interaction with the natural world. Because that world is changing more rapidly and to a greater extent than ever in human history, individuals may experience great changes in their interactions with nature and so perceive their values as under assault. The boy we saw delighting in the drum-net of Murray crays has become an adult concerned about their fate, for they are now worryingly uncommon. Did he contribute towards their decline through over-fishing? Or is it due to the vast numbers of European carp that have swept down the Murray River system, or to altered temperatures of stored waters when released into the rivers, or to modified water chemistry resulting from diversion of water to irrigation? Whatever the cause, to one observer the quality of his interaction with the place has changed and the cultural value of biodiversity no longer matches his childhood memories. The focus of each individual's concern is likely to be different, of course; furthermore, the activities that are causing change are often bringing benefit to someone else. Balancing the risks against the benefits elsewhere is essential if the results of our decisions are to meet the needs of society at large – and understanding the inter-linkages between biodiversity and human societies is a first step in such assessment.

BIODIVERSITY: SCIENCE AND SOLUTIONS FOR AUSTRALIA

Is it curious to find a scientific account of biodiversity opening with a discussion of values? It should not be seen so, because science is a human activity after all, drawing from many wellsprings of human inspiration. More particularly, biodiversity is such a broad-ranging concept that it simply cannot be understood – or, more importantly, made useful – if these background motivations for caring about it are left unstated. Given that the concept has its roots in the conservation movement, with the express objective of influencing the manner in which society reaches decisions on the use of natural resources, then the use of the notion of biodiversity quickly ramifies into political consequences. When we add to this the fact that biodiversity as a scientific concept remains broad, the need for frankness about our values becomes even more pronounced.

As a member of CSIRO, each contributor to this book recognises her or his obligation to be an impartial and respected source of information and advice on science for the community and government. Our authors aim to assist society in finding solutions to the challenges represented in biodiversity management, and in identifying means by which new opportunities might be seized. In short, this book is about options for Australia, underpinned by our best efforts to produce impartial science that can help guide the nation towards decisions on 'preferred' or 'best' solutions to any specific aspect of the challenge.

CSIRO biodiversity scientists at work in a rainforest stream. Photo: David Westcott, CSIRO.

While our authors write from the perspective of science we are also human beings, with deeply held values affecting our activities. Unsurprisingly, each of the authors reflects a commitment to scientific values in the very choice of a career. Most contributors, as scientists, also share a personal belief in the significance of growing evidence that biodiversity is linked to life-support; the importance we assign to the rapid decline in biodiversity reflects a human concern for the living planet. We have written this book to provide a bridge from the scientific literature on biodiversity to the wider community and because the value of biodiversity to life support is important to us. However, the book offers impartial information achieved through the established scientific methods: of testing ideas against critical data, and subsequent peer review and scrutiny of the results to remove gaps and mistakes. We do our best to present trustworthy advice about options for Australia in managing its natural resources.

Hence this book focuses on science and its application in response to change in the Australian landscape. A brief summary only is given of the nature and status of the continent's biodiversity, for many other texts already provide such information. Instead, our spotlight is on options for responding to the variety of values placed by members of society upon the natural diversity of Australia, and thereby for managing it better. The book does not shy away from the problems inherent in translating such a broad canvas of values into pragmatic actions. Indeed, it is written in the firm belief that a dialogue between science and society is necessary to bring clarity to our shared objectives for improved management. Such a conversation is needed not only on behalf of those wonderful creatures with which we share our continent, but also in recognition of a responsibility to hand on a healthy place for future generations.

FURTHER READING

Australian Government Department of the Environment, Water, Heritage and the Arts (2008) *Assessment of Australia's Terrestrial Biodiversity*. Department of the Environment, Water, Heritage and the Arts, Canberra. <http://www.environment.gov.au/biodiversity/publications/terrestrial-assessment/index.html>.

State of the Environment Committee (2011) *Australia State of the Environment 2011: Independent Report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities*. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra. <http://www.environment.gov.au/topics/science-and-research/state-environment-reporting/soe-2011>.

Australia's biodiversity: major features

Leo Joseph, David K. Yeates, Joseph Miller, David Spratt, Daniel Gledhill and Alan Butler

Key messages

- In the millions of years since Australia separated from Antarctica and drifted north, our continent's biodiversity has evolved mostly in isolation, while periodically taking on new 'passengers' from Asia.
- Australia's biodiversity has been greatly influenced by isolation and drying; as the continent's climate became increasingly arid and variable over the last 25 million years, fire increased in prevalence and has been a powerful evolutionary force on terrestrial life.
- Compared with those from the arid zone, the plants and animals of wetter coastal habitats are often on older, deeper branches of the evolutionary tree, particularly in the hotspots of diversity in the Wet Tropics rainforests and the south-west corner of Western Australia.
- Most of Australia's territory is marine; it contains one of the most diverse arrays of organisms worldwide, reflected in the Great Barrier Reef and along the southern coast.
- The majority of species of Australia's fauna and flora, both terrestrial and marine, are still being discovered and described.
- Modern DNA analysis is revealing ever more surprises about the evolution of Australian biodiversity, reinforcing its special place in the world's natural heritage.

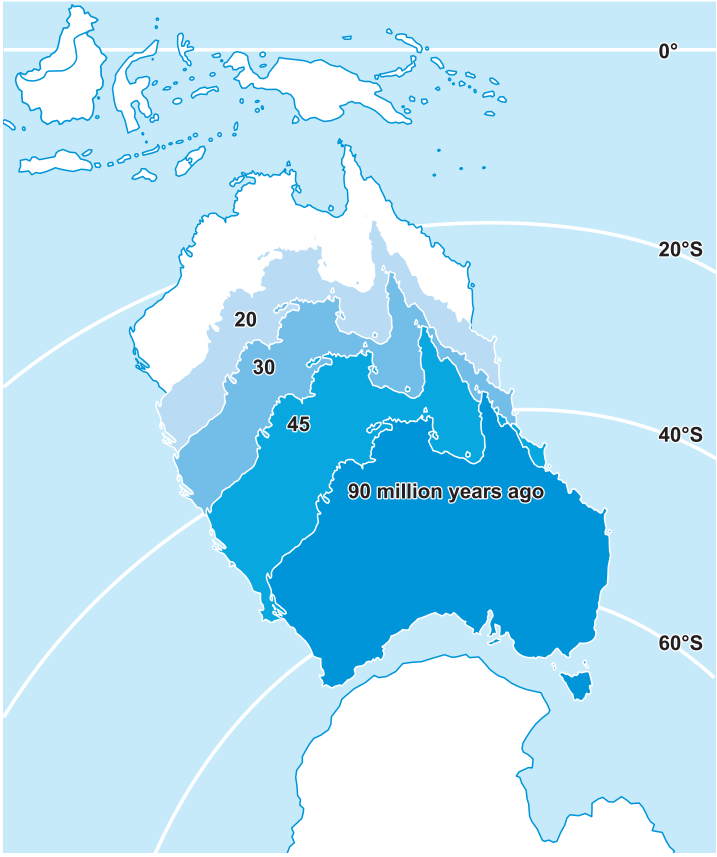
GLOBAL CONTEXT: HOW AND WHY AUSTRALIAN BIODIVERSITY IS SPECIAL

Australia is renowned for its biodiversity. Why is our biodiversity so distinctive, and why is it important that we understand the origins, connections, and differences of individual plants and animals? This chapter builds on the idea that understanding the evolution of Australian biodiversity deepens our appreciation of the living organisms with which we share our continent and its seas. The fact that Australian biodiversity is of profound scientific value, though, is only one reason for wishing to uncover its secrets: we also want to improve knowledge so as to guide conservation, environmental management and biosecurity. This chapter gives an overview of our current knowledge about Australia's biodiversity. To develop effective management, we need to know what we are dealing with, how it got there, and the differences and similarities with other parts of the world. The chapter outlines essential elements of Australia's biodiversity in this context.

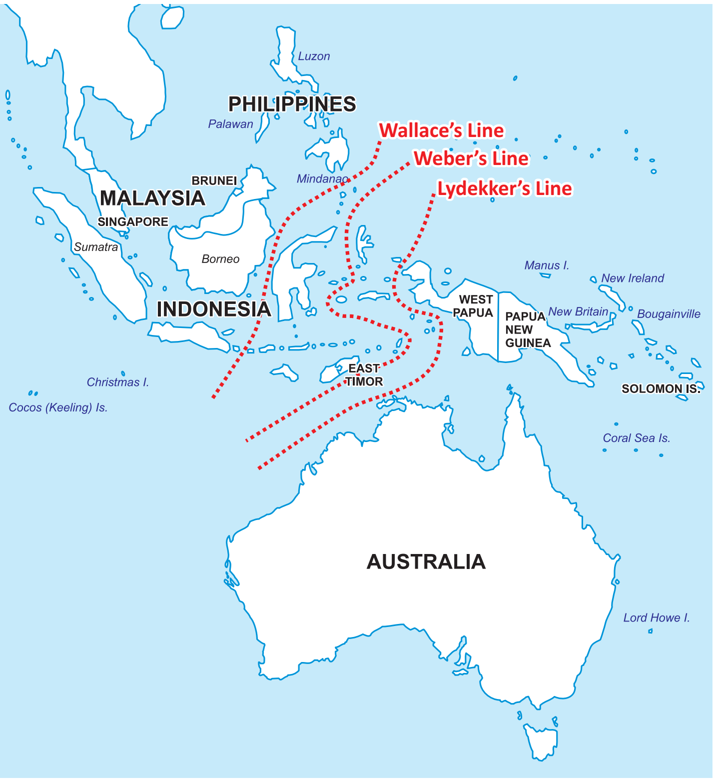
Origins and history

Australia's separation from Antarctica during the break-up of the ancient super-continent Gondwana began approximately 85 million years ago and was complete 30 million years ago, so it has been isolated through much of the last 65 million years (Figure 2.1).[1] Furthermore, during the Pleistocene (the geological epoch lasting from 2.6 million to 12 000 years ago), there were many changes in sea level that rearranged the connections between Australia's coast and the islands of present-day Indonesia and New Guinea. This geological history has provided the two key benefits of isolation and time which evolutionary processes require for the modification of existing species and generation of new species. The long process of continental drift itself is a third ingredient that constantly moulds the shapes and positions of the world's continents and, thus, how organisms can disperse among them.

The continental plate on which Australia is rafting northward first collided with the Eurasian plate approximately 25 million years ago. New combinations of species and ecosystems appeared as land-bridges allowed dispersal and intermixing. Biologists have long recognised the result of this collision by drawing lines on maps – such as Wallace's Line – to mark out regions that have different complements of biodiversity (Figure 2.2). Many organisms such as fishes, corals, crustaceans and birds have distinctive representatives on either side of the Line, and still others occur only on one side of it. Although many marine species disperse over huge distances, surprisingly there are also many unable to colonise new areas readily, either because they lack dispersive life-stages or because unfavourable currents act as barriers. Such species are still limited today to the geological structures on which they arrived from Gondwana. Some migratory birds, however, can fly over such lines with ease (Box 2.1).



▸ ***Figure 2.1***: *Diagram showing the northward movement of Australia as it separated from Antarctica. Australia's approximate position at 90 (prior to separation), 45, 30 (separation now complete) and 20 million years ago, and the present day is shown.*[2]



▸ ***Figure 2.2***: *Locations of three 'biogeographical lines' that have been proposed to differentiate the faunas and floras of the Australian, New Guinean and Pacific regions to the east of the lines, from the Asian and European regions to their west. Each is named after a biogeographer; Wallace's Line, first proposed by Alfred R. Wallace, is the most widely recognised of these lines.*

Box 2.1: Migratory birds and Wallace's Line

Most birds that migrate within Australia are land birds or waterfowl such as ducks. They may have regular or irregular patterns of movements, but do not move north of Wallace's Line. Just a few groups of birds (although millions of individuals are involved) move between the northern and southern hemispheres across Wallace's Line. Migratory shorebirds are one such example. They are unaffected by Wallace's Line, moving between breeding grounds in the northern hemisphere and non-breeding grounds in the Australian region.[3]

(a) *Among a flock of various species of shorebirds, mostly bar-tailed godwits,* Limosa lapponica, *one stands out with its yellow leg flag-coded. This indicates to any observer where on its migratory pathway the bird was flagged – in this case Broome, Western Australia.* ***(b)*** *Shorebirds gather in their thousands on the north-west coast of Australia before beginning their northwards migration to breeding grounds as far away as Siberia. Here, something can be appreciated of the scale of these flocks. Photos: Clare Morton.*

Evolutionary biologists find the challenge of identifying evolutionary links between components of Australia's biodiversity and that on other Gondwanan remnants, such as South America and New Zealand, to be fascinating but difficult. Did species such as bunya pines and their relatives in the genus *Araucaria* attain their current patchy distributions through passive drifting after the break-up of Gondwana? Or were their ancestors widespread before Australia drifted north, such that extinction and dispersal created the present distributions? These types of questions may be resolved by examining the record contained in the genetic make-up of species as encoded in their DNA, as well as by studying the form of today's plants and animals (i.e. morphology), and fossils.[4] We find that the answers are complex and vary with species, as shown in Table 2.1.

Table 2.1: Examples of vertebrate animals of differing evolutionary origins[5,6]

Originated in Gondwana before Gondwana break-up	Arrived in Australia after break-up	Uncertain
Geckos of the families Diplodactylidae, Carphodactylidae and Pygopodidae	Other geckos, some skinks, dragon lizards, front-fanged elapid snakes, blind snakes and pythons	Ratite birds such as emus and cassowaries in Australia, and rheas, ostriches, moas and kiwis elsewhere

Whatever the particular cause, though, elements of Australia's biodiversity are related to groups elsewhere in Gondwana's remnants. For example, mound-building birds such as the mallee fowl, *Leipoa ocellata*, have closest living relatives in South and Central America (the curassows and guans),[6] and the Maugean skate, *Zearaja maugeana*, a ray found in estuaries in south-western Tasmania, has its closest living relatives in New Zealand and South America.[7] The challenge is to understand how these relationships do or do not explain present-day distributions.

Australia's Gondwanan inheritance is evident in the rainforest fragments along its eastern seaboard, especially the unique rainforest plants of the World Heritage-listed Wet Tropics. Sixteen of the 28 ancestral lines that branched off early in the history of flowering plants are present today in the Wet Tropics, and include species that occur nowhere else in the world. Conditions have remained suitable for these plants since Australia separated from Antarctica, so the Wet Tropics is a global refuge for these early branches of the evolutionary tree of plants. Of course, evolution has continued in the Wet Tropics since the break-up of Gondwana, and today's vegetation reflects dispersal, speciation and divergence in a flora of multiple origins.[4]

The period following separation from Gondwana is known as the Miocene Epoch, lasting from approximately 23 million years ago to 5.3 million years ago, when Australia began drying (Figure 2.3). The Miocene Epoch saw the evolutionary origin of many present-day lineages, including both *Eucalyptus* and *Acacia*. Following the next epoch, the Pliocene, came the turbulent Pleistocene, from 2.6 million years to 12 000 years ago. Globally, it was a time of cyclical climatic upheavals, and there were repeated, lengthy glaciations in the northern hemisphere. In Australia, terrestrial environments mostly remained free of ice, although they experienced cycles of severely cold, dry climates. The most recent cycle, the Last Glacial Maximum at 20 000 years ago, was cold, arid and windy. These circumstances moulded the geographical distributions and genetic diversity of many of Australia's present-day species.

GEOLOGICAL TIME SCALE

ERA	PERIOD	EPOCH	MILLION YEARS BEFORE PRESENT DAY
Cenozoic	Quaternary	Holocene	0.012
		Pleistocene	2.6
	Neogene	Pliocene	5.3
		Miocene	23
	Paleogene	Oligocene	34
		Eocene	56
		Paleocene	66
Mesozoic	Cretaceous		145
	Jurassic		201
	Triassic		252

▸ ***Figure 2.3***: *The geological epochs pertinent to this chapter. Much of the history discussed here in relation to the evolution of Australian biodiversity happened from the Cretaceous through to the present day. In particular, the drying out of Australia began in the Miocene. The Pleistocene saw worldwide cycles of glaciation, which shaped and moulded pre-existing biodiversity into present-day patterns.*

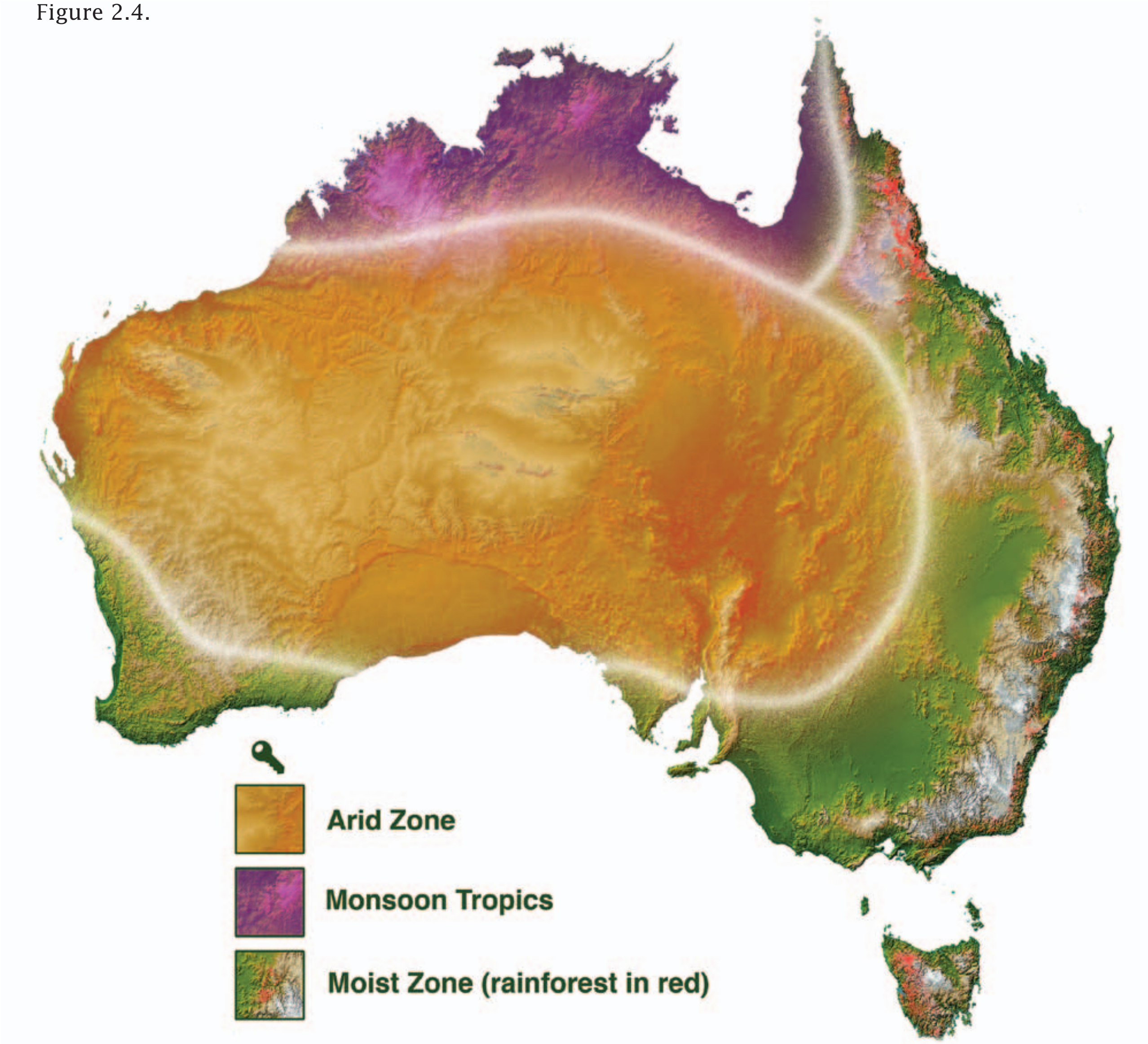
The dispersal and distribution of terrestrial animals, including humans, and diversification among some near-shore marine species, were also affected by sea level changes in the Pleistocene. Land-bridges were exposed when glaciers locked sea water into the polar ice-caps, thereby drastically lowering sea levels. Oceanic temperature changes also caused splitting of ancestral marine species into new, daughter species.

Fire began shaping Australian biodiversity, at least since drying set in during the Miocene. Banksias, for example, require the heat of a fire before their fruits will open and expose the seeds for dispersal. After a fire, eucalypts often produce new growth along trunks and branches, known as 'epicormic re-sprouting'. Whether fire drove the evolutionary change in eucalypts, however, or whether the eucalypts themselves created flammability in vegetation for some other reasons, remains uncertain.[8]

Epicormic growth on eucalypts after fire. ***(a)*** *Close-up of an epicormic sprout on a eucalypt four months after Black Saturday bushfires, Strathewen, Victoria, and* ***(b)*** *a view of a eucalypt forest showing epicormic growth three years after a fire, Tidbinbilla, Australian Capital Territory. Photos: (a) Robert Kerton, (b) Murray Fagg.*

AUSTRALIAN BIOMES

Australia's terrestrial biomes – entire landscapes and the species inhabiting them – are depicted in Figure 2.4.



▲ ***Figure 2.4**: Many schemes have been proposed to illustrate how the Australian continent can be divided up into biomes or biogeographical regions, each with a distinctive complement of fauna and flora. Common to most such proposals is a vast, inland arid zone (orange), a northern tropical region spanning the continent from east to west (purple), and wetter regions of tropical to temperate habitats in eastern and south-western Australia (green and red).*

Terrestrial environments

The arid zone

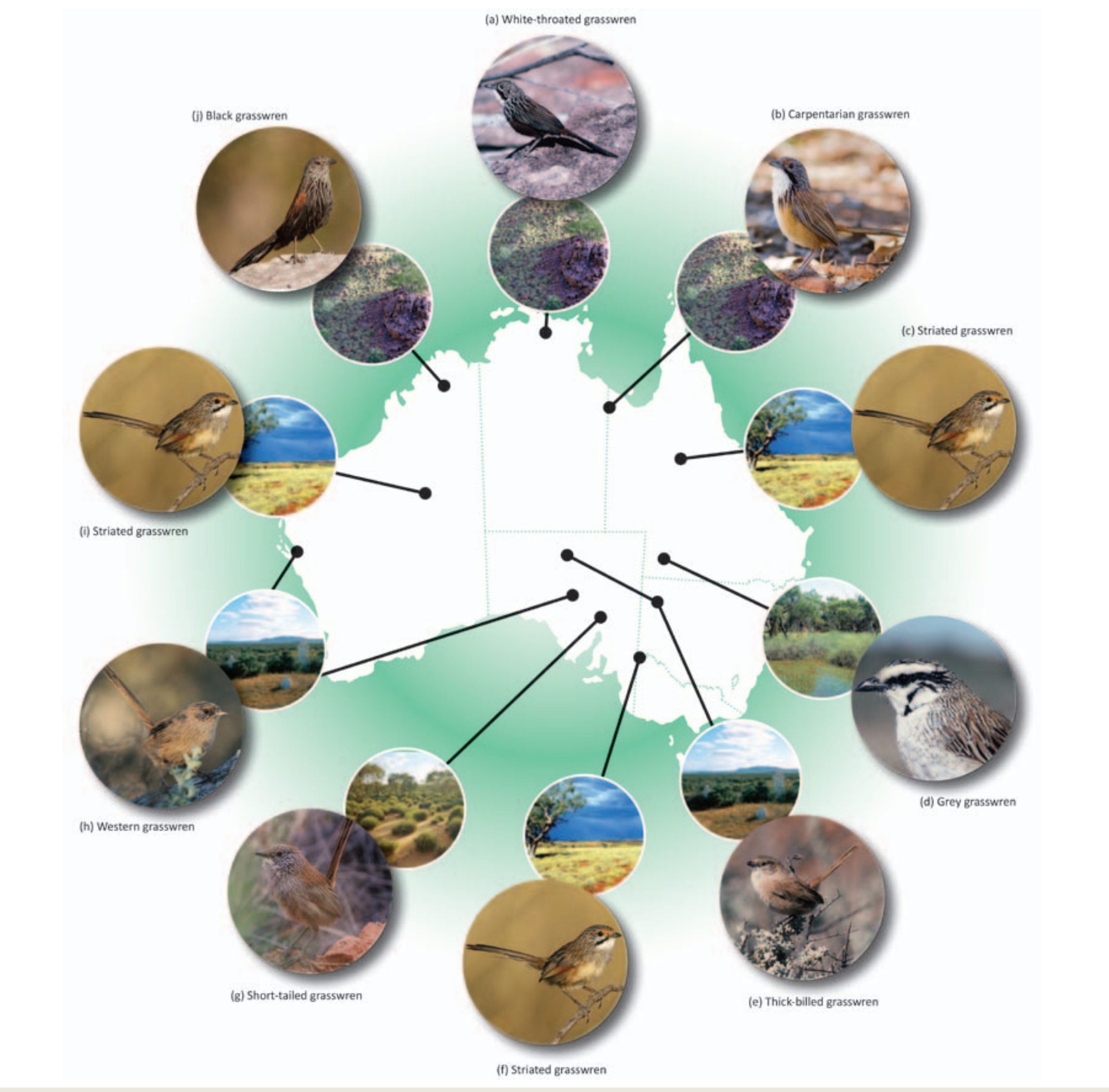
Australia's arid zone dominates the centre and west of the continent, excluding the monsoonal tropics and moist zone in the south-west. It is a series of deserts, each infertile because of long-term weathering of soils. Yet, after rain, the deserts are flush with plant productivity, far from the popular image of Sahara-like sand dunes. In the arid zone, lizards known as skinks have undergone one of the most strikingly diverse evolutionary radiations of any terrestrial vertebrate, and from just a few ancestors now there are 240 species.[9]

The arid zone occupies most of the Australian continent. Diverse habitats make up the arid zone, such as ***(a)*** *the stony deserts, and* ***(b)*** *the grasslands on sandplains and dunes in which spinifex,* Triodia*, is dominant. Photos: (a) Len Zell, (b) Aaron Greenville.*

Scientists long theorised that arid-zone species evolved from ancestors in wet forests and woodlands, but it is now clear that the story is more complex. Isolation of organisms, driven by fine-scale variation in soil types and the supply of groundwater across the arid zone, has caused complex evolution. Molecular studies show that, especially among animals, the deserts have been a cradle of evolution rivalling familiar 'natural laboratories' such as the Galapagos Islands (Box 2.2). Plant speciation tends to be highest, however, at the edges of the arid zone where species may arrive from other biomes.[9]

Box 2.2: Grasswrens – among the most Australian of Australian birds

Found only in Australia, grasswrens mostly inhabit grasslands of spinifex, *Triodia*, growing on sandy or rocky substrates in remote or difficult-to-access parts of arid and tropical Australia. One species inhabits canegrass swamps of inland eastern rivers. The experience of seeing these birds after difficult searches can be described as electric: the sharp white striations of their plumages on a black or chestnut ground colour, their buzzing calls, and their scurrying movements between hummocks of spinifex. Their spinifex habitats are also home to diverse groups of reptiles, insects, and even land-snails.



Grasswrens of the genus Amytornis *are members of the family Maluridae, which includes the better known fairy-wrens,* Malurus. *Not all species and their various populations could easily be shown here. Diagrammatic indications of where species occur are accompanied by photos that broadly indicate the birds' remote habitats. Habitats range from rocky spinifex-clad ranges of tropical Australia to chenopod plains, lignum swamps and mallee, especially with spinifex. Photos of birds: (a), (d), (e), (g), and (h) Lynn Pedler; (b) and (j) Mark Sanders; (c), (f), and (i) Rob Drummond. Photo of habitats: (a), (b) and (j) Tim Dolby, all others CSIRO.*

The monsoonal tropics

This region of intense annual wet and dry seasons comprises Australia's north – the Kimberley, Top End and Cape York Peninsula. Its most physically distinctive features are the basalt or sandstone escarpments and ranges of the Top End and Kimberley that also protect isolated rainforest pockets, and the region's savannas – the most extensive in the world. Once more, DNA studies reveal far more diversity than earlier had been appreciated. For example, many more toadlets of the genus *Uperoleia* have been so identified;[10] and what has long been thought of as one northern Australian species of short-eared rock-wallaby, *Petrogale brachyotis*, comprises eight geographically discrete lineages, at least some of which may eventually be recognised as separate species.[11] Among plants, too, the monsoonal tropics show high levels of recent speciation, such as in *Acacia* and *Glycine*, the wild relatives of the soybean. Many plants also have evolutionary links to Australia's near neighbours because of dispersal as the continent moved northward.[4]

Monsoonal Australia has spectacular sandstone escarpments and nearby wetlands that together form 'biodiverse islands' in a sea of eucalypt savanna. Photo: Parks Australia.

Toadlets of the genus Uperoleia *symbolise the revolution taking place in the understanding of biodiversity in monsoonal northern Australia.* Uperoleia *is the most species-rich genus (27 species) in the frog family Myobatrachidae, and the majority of the species are in the tropics. True species diversity of these frogs has long confounded scientists due to their small size and unvarying body plan, but now several new species have been described, including* Uperoleia lithomoda *from the Hervey Range, Queensland. Photo: Stewart McDonald, courtesy Renee Catullo.*

The eastern forests and woodlands

Relative to the rest of Australia, the forests and woodlands along Australia's eastern seaboard are rich in species. Diversity is generally higher in eucalypt forests, woodlands and heaths than in rainforests. Perhaps there were higher rates of extinction over evolutionary time in the relatively small remnants of the rainforests; conversely, rainforests may retain some of the oldest branches of the evolutionary tree of flowering plants. Many of the wetter biome's elements, including its rainforests, have evolved from ancestors that dispersed into Australia from the north. Over millions of years, contraction and fragmentation of habitats, extinction of some species, and dispersal inwards by others from outside the regions have contributed to the biodiversity of today.[4]

The south-west of Western Australia is effectively a western isolate of this biome. Additionally, it is a globally significant hotspot of plant biodiversity. Over 50% of plant species are endemic, generated by long-term climatic stability that provided opportunities for localised specialisation. The area has been a major evolutionary refuge during the drying of the continent for the two largest genera of Australian plants, *Acacia* and *Eucalyptus*.[4]

Forests and woodlands of temperate eastern Australia. ***(a)*** *Regenerating mountain ash,* Eucalyptus regnans, *decades after the 1939 bushfires, Donna Buang Road, Victoria.* ***(b)*** *From Mount St Leonard, Victoria, looking south towards the Victorian Central Highlands.* ***(c)*** *Rainforest gully with tree ferns,* Dicksonia antarctica, *Donna Buang Rainforest Gallery Walk, Victoria.* ***(d)*** *Spotted gum forest,* Corymbia maculata, *with understorey of cycads,* Macrozamia communis, *Potato Point, NSW South Coast. Photos: Stephen Roxburgh.*

Gilbert's potoroo, Potorous gilbertii*, is an example of a species found only in south-western Western Australia. It was thought extinct for more than 100 years; it was rediscovered in 1994 and is now the subject of successful community conservation and research. Photo: Dick Walker, Gilbert's Potoroo Action Group (www.potoroo.org).*

Marine environments

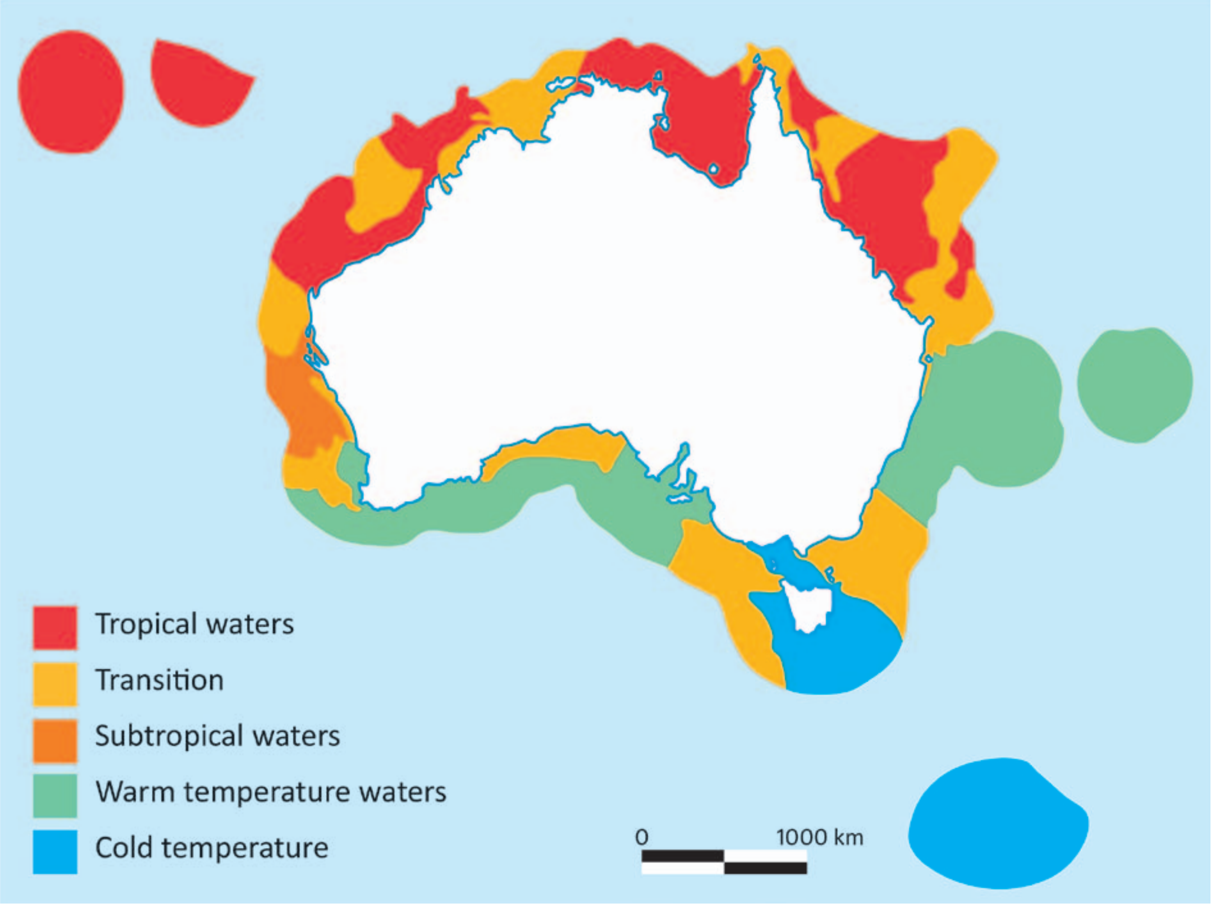
Marine environments are equally diverse. Aside from gross differences from place to place – the water column, the bottom of the continental shelf, or even deeper on the sea floor's abyssal plain – many factors govern evolution and distribution of marine organisms: climate, water temperature, salinity, light and nutrients, or presence of habitat such as soft sediments. Scientists divide the environment into depth-related zones: the intertidal, coastal, neritic (the water column over the continental shelf), or abyssal (deeper than 2000 m). Even mobile species cannot always move freely to new zones, or across deep-water trenches, and many organisms are attached to the sea floor. The distribution of organisms is influenced by where their juvenile forms (larvae) eventually attach as adults, and whether their eggs remain on the sea floor or drift with the currents. Overlying these effects are climatic and biogeographic differences among large regions, such that we can recognise several marine bioregions around Australia (Figure 2.5).[12]

The tropical zone

This zone is characterised by coral reefs and shorelines fringed with mangroves, with much in common with seas of the Coral Triangle (Papua New Guinea, Indonesia and the Philippines, plus Australia). Species diversity in the tropical zone is high. A common pattern is that of closely related but distinct species replacing each other geographically from east to west, partially because of separation of each pair's common ancestor on the two sides of the land-bridge during periods of low sea level.[12]

The warm temperate zone

This is where the shallow sea floor is dominated by seaweeds and seagrasses rather than by corals, and with correspondingly different species of fishes, invertebrates and plants. Along the south coast, in particular, there are high numbers of endemic species of animals and seaweeds. Again, there are distinctions between eastern and western Australia. There are complicated overlaps along the southern margin of the continent, partly due to the past isolation of ancestral populations by a land-bridge connecting Tasmania to the mainland when sea level was lower in the Pleistocene.[12]



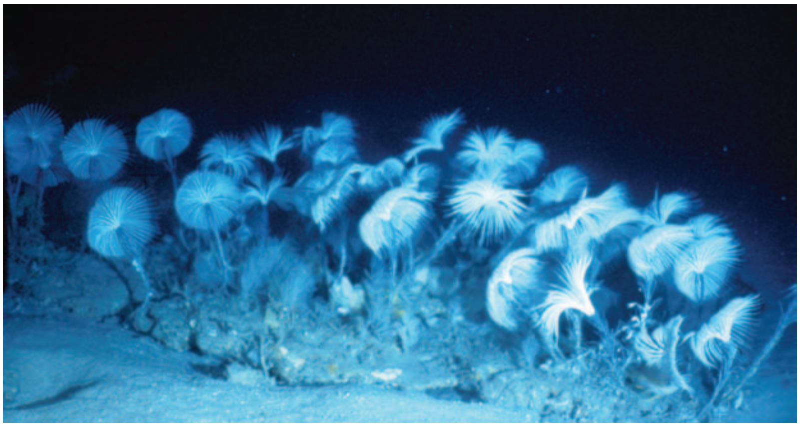
▲ ***Figure 2.5***: *Seafloor marine bioregions of Australia. Adapted from www.environment.gov.au/coasts/mbp/imcra/nmb.html.*

The cool temperate zone

Cool waters around Tasmania support fewer species than tropical waters, but may have higher proportions of endemic species. Forests of giant kelp, *Macrocystis pyrifera*, occur nowhere else in Australia (though they form in cold waters elsewhere in the world). Other examples include a newly discovered species of sand fish, *Lesueurina*, which is confined to the south coast of Tasmania, and an alga, *Cystoseira trinodis*, limited just to Blackmans Bay, Tasmania.[12]

Canyons

For millennia, sea water flowing across the continental shelf has tumbled into underwater cascades across Australia's continental slopes, carving deep canyons – the Perth Canyon off the Swan River, Western Australia, the Murray Canyons from the mouth of the Murray River, South Australia, and, even more spectacularly, the Tasman Fracture Zone in deeper water south-west of Tasmania, a relic of the rifting of Australia from Antarctica. The Tasman Fracture Zone contains a canyon over 400 km long, and because of its striking nature is included in a Marine Protected Area. The rocky walls of marine canyons are habitats for rich and varied organisms that prosper in the rapid

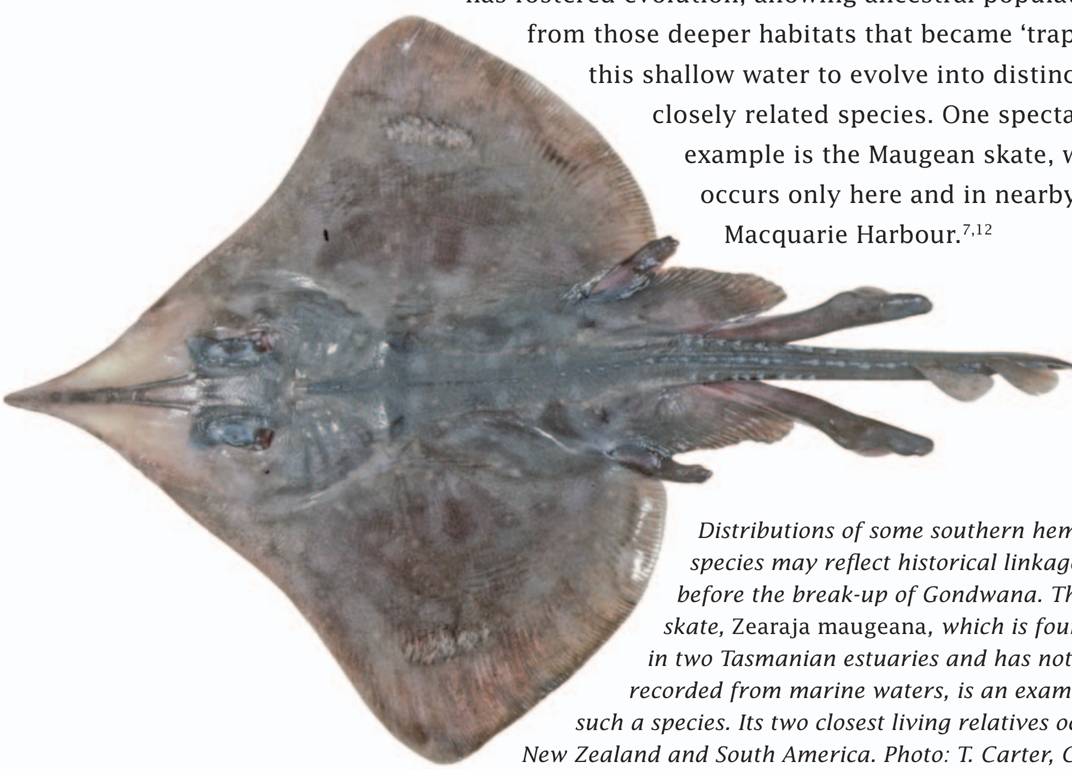


Stalked crinoids or sea lilies, Metacrinus cyaneus, *are echinoderms related to seastars and sea urchins. This species, occurring on the edge of Australia's southern continental shelf, is notable as a 'living fossil' – many of its relatives are extinct, and the form has remained the same for a long time. Photo: CSIRO.*

currents, among them soft corals, sponges, bryozoans and stalked crinoids. The canyons are also home to many large fishes, and in some cases constitute spawning or nursery areas for a range of commercial species.[12]

Estuaries

Estuaries straddle land and sea as they mix fresh and saline waters. Port Davey and Bathurst Harbour, in south-west Tasmania, make up an estuary with a difference. Long isolated, and cold by Australian standards, its waters carry a surface layer stained dark from tannins flowing from the adjacent rainforests. This layer reduces penetration by light, thereby making even shallow waters and the animals in them resemble deeper waters far down the continental slope. Isolation has fostered evolution, allowing ancestral populations from those deeper habitats that became 'trapped' in this shallow water to evolve into distinctive but closely related species. One spectacular example is the Maugean skate, which occurs only here and in nearby Macquarie Harbour.[7,12]



Distributions of some southern hemisphere species may reflect historical linkages from before the break-up of Gondwana. The Maugean skate, Zearaja maugeana, *which is found only in two Tasmanian estuaries and has not been recorded from marine waters, is an example of such a species. Its two closest living relatives occur in New Zealand and South America. Photo: T. Carter, CSIRO.*

SOME AUSTRALIAN BIODIVERSITY ICONS

Having briefly surveyed Australia's major biomes, we now look at some of our best-known examples of biodiversity.

Terrestrial plants and animals

Australia's approximately 140 species of marsupials, the pouch-bearing mammals, are among the natural wonders of the world. They evolved to live in almost every terrestrial ecosystem; the only thing they do not do is feed on flying insects, which remains the job of birds and bats. There are marsupial species that burrow through sand, live on trees and shrubs, inhabit rock piles, rainforest canopies, and deserts, and even species that glide through the air. Australia is also home to two species of egg-laying mammals, the platypus and echidna. These special mammals are also known as monotremes, which means 'single opening' – that is, they have a single opening for reproduction, urination and defecation. Echidnas are also represented in New Guinea. Both of these groups of mammals contrast with placental mammals, which are distinctive in giving birth to well-developed young. Among the placental mammals, Australia has a diverse range of bats and rodents.[13]

Some of Australia's unique mammals: ***(a)*** *a western grey kangaroo,* Macropus fuliginosus, ***(b)*** *an echidna,* Tachyglossus aculeatus, ***(c)*** *a platypus,* Ornithorhynchus anatinus, *and* ***(d)*** *a koala,* Phascolarctos cinereus. *Photos: (a) and (d) Bruce Webber, CSIRO, (b) Willem van Aken, CSIRO, (c) Healesville Sanctuary.*

Woodlands dominated by mulga, Acacia aneura, *typify vast parts of inland Australia, occurring on rock and sand and often with understoreys that spring to life after rain. Photo: Joe Miller.*

(a) *A scribbly gum moth,* Ogmograptis racemosa, *and* **(b)** *a scribbly gum,* Eucalyptus haemastoma, *showing the scribbles that are diagnostic of particular species of moths. Photos: (a) Carla Flores and Marianne Horak, (b) Natalie Barnett.*

The eucalypts and acacias are examples of the power of isolation in evolution, and today they dominate vast tracts of the continent (but see Box 2.3). With over 1000 species, *Acacia* is the largest plant genus in Australia, and there are also nearly 700 eucalypts, with both being notably diverse in south-western Australia. Nodules on the roots of *Acacia* contain special bacteria that absorb nitrogen from the air and make it available as ammonia to the host plant, a process vital for plant survival and thereby a factor in assisting diversification of *Acacia* in the face of infertile soils. *Acacia* and *Eucalyptus* also host a spectacular diversity of insects and fungi. A familiar example is the scribbly gum moth, whose larvae feed on tissues just below the epidermal cells of tree trunks to produce the 'scribbles' so often seen on gum trees.[14]

Many of Australia's birds are as Australian as kangaroos and gum trees. Resemblances to northern hemisphere namesakes, such as robins and wrens, reflect convergent evolution – the process by which unrelated species performing similar roles evolve to resemble one another.[15]

The mallee emu-wren, Stipiturus mallee, *is a member of the Maluridae, a family of birds unique to Australia and New Guinea. The word 'wren' reflects the difficulty Europeans had when they first tried to name many Australian birds; there is no close relationship to northern hemisphere wrens, although because they perform similar roles in the ecosystem they have come to resemble them superficially. Photo: Simon Bennett.*

The major plant-eating animals in Australia might best be thought of as termites rather than the more familiar kangaroos and wallabies. Strictly decomposers rather than grazers of vegetation, termites are akin to ecosystem engineers in northern Australia's tropical savannas, where infertile soils and seasonal rainfall mean that the populations of large herbivorous mammals that one finds in African savannas are absent. Famous for their mounds, which store harvested plant material, termites also help store water in soils by creating numerous openings into the ground.[16] Australia is also a global centre of ant diversity. In most regions of the world, rainforests have the richest ant diversity, whereas in Australia the richest areas are the deserts and savannas. Put simply, termites, ants and other invertebrates like earthworms maintain nutrient cycling and ecosystem function across most of Australia.[17]

Abundant termite mounds in most monsoonal Australian landscapes demonstrate the importance of these animals in maintaining a flow of nutrients through grasslands and woodlands. Photos: (a) Leigh Hunt, (b) Adam Liedloff, CSIRO.

Box 2.3: An enduring question – why are there palm trees in central Australia?

Scattered among the eucalypts and acacias of arid inland Australia are some unusual plants, among them the palms, *Livistona*, of central Australia. The answer to their puzzling presence reveals how interconnected biomes may be in evolutionary terms. One argument was that Palm Valley has been a refuge for plants since the mid-Pleistocene. The notion was that water has been stored in sediments around the Valley over time-spans of 100 000 years or more, such that some plants endured through arid phases of the Pleistocene. However, the hypothesis that the palm is an ancient relic is not supported by the evidence. Genetic studies reveal instead that a single *Livistona* ancestor colonised Australia from the north 10–17 million years ago, and that the populations in Palm Valley could have been established by immigrant seeds from the Roper River about 15 000 years ago. It is most likely that the palms are a legacy of dispersal, either by Aborigines or by birds and other animals.[18]

The low vegetation typical of arid Australia is in stark contrast with tall Livistona*, Palm Valley, Northern Territory. Photo: Jurriaan Persyn.*

Marine plants and animals

Sharks and rays are fishes characterised by skeletons made of cartilage rather than bone. Australian marine and estuarine waters support more than 320 species, representing 25% of the global total. Some barely exceed 20 cm, such as the small-eye pygmy shark, *Squaliolus aliae*, whereas the largest whale sharks, *Rhincodon typus*, exceed 12 m. New samples and methods reveal under-appreciated richness, with around 100 new Australian species having been recently described. Nearly half of the 11 known species of wobbegong sharks have been recognised only since 2001.[19]

Most of us know that there are strange animals in the deep, such as angler fish and giant squid, but an equivalent world of smaller organisms goes unnoticed. Sea floor 'grab' samples can contain hundreds of individual invertebrate animals and dozens of species. Specimens are sent to specialists around the world for examination and naming. It is remarkable how many species there are, how sparsely scattered they seem to be, and how few have been seen before. A recent voyage off Western Australia collected 108 species of sponges (70% of them new to science), 141 species of soft corals (80% new), 462 species of molluscs (67% new), 326 species of echinoderms (38% new), 529 species of crustaceans (30% new), over 50 species of ascidians (80% new) and 74 species of polychaete worms (30% new). Most were rare, and 50% of species occurred in only one sample!

Grab-sampling: from a staggering diversity of mostly undescribed organisms heaved out of the ocean during surveys of marine biodiversity, preliminary sorting into major groups sets the scene for later study. The scale of undescribed diversity in the oceans begins to be apparent from such trawls. Photo: Alan Butler, CSIRO.

Reef-building corals are well known in shallow tropical waters. In Australia's cold waters, however, there are horny and soft corals as well as stony corals that lack the symbiotic algae of tropical corals. On seamounts south of Tasmania they form spectacular 'forests' – not like the reefs in tropical seas but certainly a habitat for many kinds of animals. They grow very slowly: some have been aged at over 300 years (and perhaps thousands).

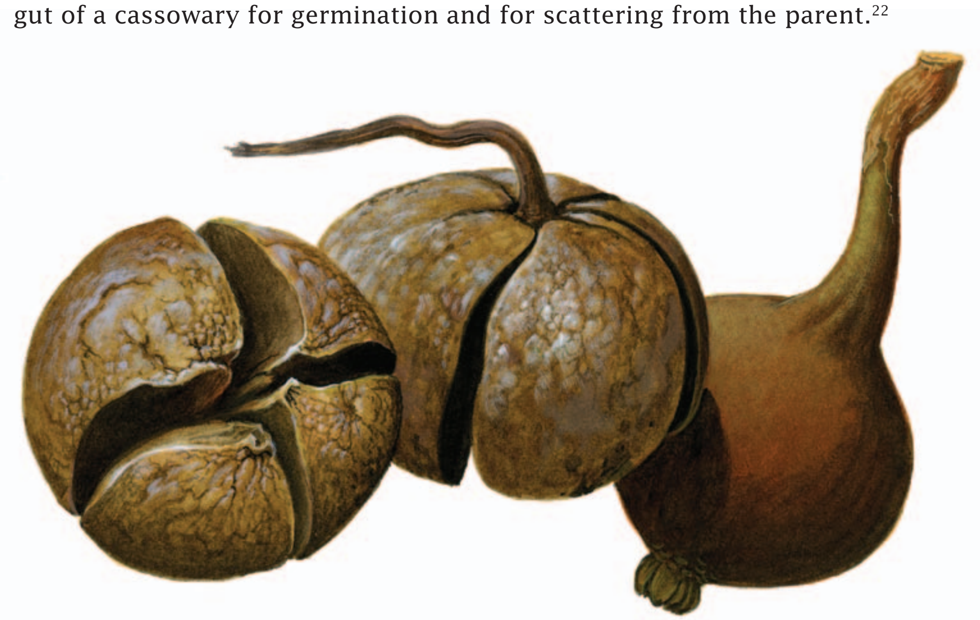
Parasites

Perhaps it is an unusual honour, but Australia possesses one of the most spectacular radiations of internal mammalian parasites in the world. The nematodes of kangaroos, wallabies and potoroos comprise 39 genera and 294 described species in one subfamily, the Cloacininae. The complex fore-stomach of the kangaroos is the centre of fermentative digestion, rather than the bowel as in placental mammals, so setting the evolutionary stage for this radiation. The marsupial hosts themselves came into being within the last 10 million years, so the evolution of the parasites can be dated to this time.[20]

Extinction of the megafauna and its aftermath

Just a few thousand years ago, Australia's terrestrial and marine environments were inhabited by many more very large species than today. Among this 'megafauna' in Australian seas and elsewhere was an enormous shark, *Carcharodon megalodon*, estimated to have reached 16 m in length and to have had teeth 17 cm long. It died out approximately 1.5 million years ago. On land, enormous marsupials became extinct as recently as 40 000 years ago. The giant grazer, *Diprotodon*, and the marsupial lion, *Thylacoleo*, are among the more famous. Explanations for their extinction are contentious. Did the arrival of humans lead to their extinction through hunting – or was climate change the cause? Perhaps both, but population modelling suggests that such animals were at risk of extinction under even low levels of hunting due to their slow rates of reproduction.[21]

Plants, too, tell of the extinct megafauna. In the Wet Tropics, fruit of the tree *Idiospermum australiense* are the largest of any Australian plant, weighing 225 g and measuring 8 cm in diameter. No living animal can swallow the fruit, which are starchy and contain toxins. Although musky rat-kangaroos, *Hypsiprymnodon moschatus*, may move and bury the seeds, the primary means of dispersal now is to roll downhill. We can only ask whether its seeds were once dispersed by giant animals, in the way some rainforest tree seeds today require passage through the gut of a cassowary for germination and for scattering from the parent.[22]



A painting of the fruits of the rainforest tree Idiospermum australiense*, which is unique to the Wet Tropics. Each fruit is about 8 cm across and cannot be swallowed by any living animal. Its primary means of dispersal is to roll downhill. Painting: WT Cooper.*

SPECTACULAR YET CRYPTIC RADIATIONS OF BIODIVERSITY

The molecular revolution of DNA analysis, and advances in sampling techniques, have led to the discovery of many unusual species among notable groups of organisms. This section discusses a few highlights.

Orchids

Australia is home to over 200 genera of orchids, including not only familiar species that are terrestrial and epiphytic (i.e. living on but not parasitising trees) but also the underground orchid, *Rhizanthella*. Orchid taxonomists have tended to split populations into separate species, although recent DNA analysis does not support many of these divisions. On the other hand, intriguing work in the genus *Chiloglottis* suggests that different species are visually similar but use very different chemical odours to attract their insect pollinators.[23]

Reptiles and amphibians

Australian desert reptiles have long been known to be rich in species, and now the molecular revolution has revealed even more diversity. Descriptions of new species in the last decade show the scale of the revolution in Australian reptiles and amphibians: a new desert taipan as venomous as its two closest relatives; a new goanna from the Pilbara; some 15 new species of frogs from across the continent; several new dragon-lizards from the deserts of Queensland and Western Australia; several new species in three genera of skinks; and new leaf-tailed geckos. The Kimberley, in particular, is emerging as a hotspot of new reptile and amphibian species.[24]

Stygofauna

An unusually rich example of stygofauna – animals such as aquatic beetles living underground – was discovered in the Yilgarn region of Western Australia in the late 1990s. This radiation of stygofauna has emerged as one of the world's most spectacular, having occurred in groundwaters ranging from freshwater to marine salinities, in both coastal and continental locations. The range of habitats and water quality, as well as the variety of evolutionary origins of the fauna, all help explain the stygofauna's diversity. Typically, species have tiny geographical ranges associated solely with local aquifers.[25]

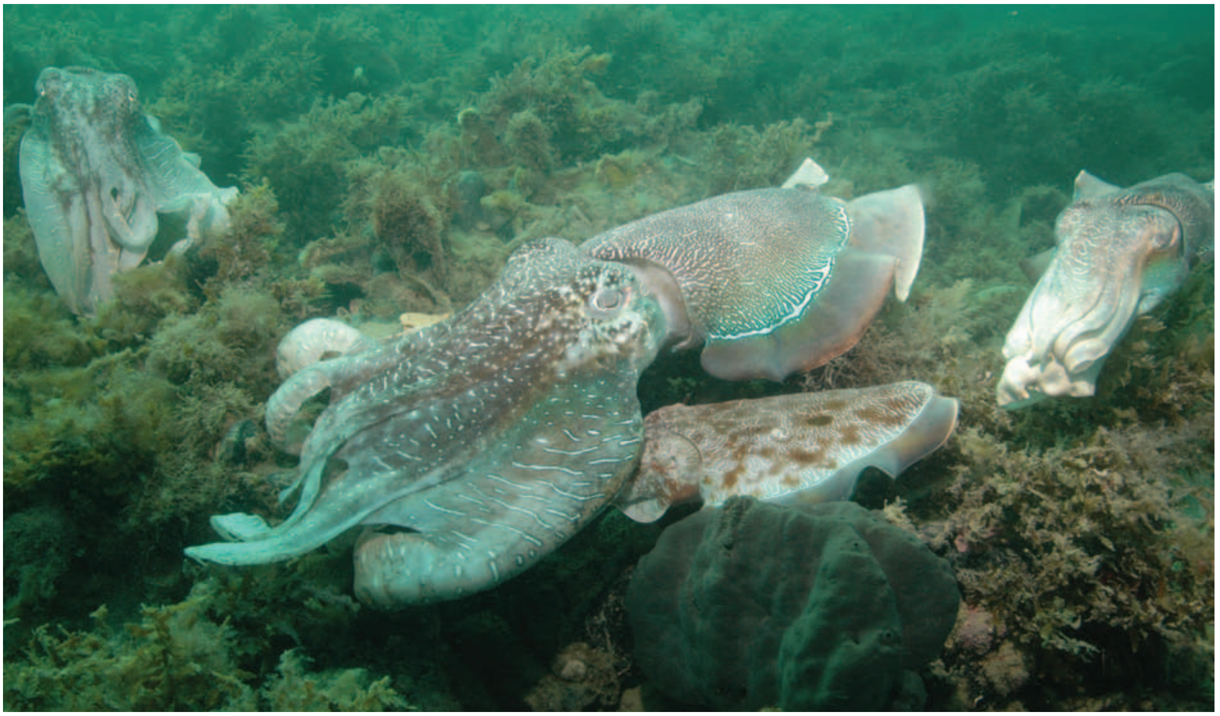
Handfish

Among Australia's many unique marine species are the aptly named handfishes (family Brachionichthyidae), which have modified fins on which they 'gallop' across the floor of estuaries and seas between 2 and 30 m in depth. A fossil handfish is known from Italy from some 50 million years ago, but the 14 living species occur only in southern and eastern Australian waters and seven are restricted to Tasmania.[26]

A spotted handfish, one of Australia's most unusual marine species, pictured with its egg-mass. Living members of the family survive only in temperate Australian waters although fossils have been found in the present-day northern hemisphere. Photo: CSIRO.

Cuttlefish

Australia is home to some special cuttlefish, squid and octopus. The giant cuttlefish, *Sepia apama*, is the largest cuttlefish in the world, sometimes reaching a metre in length, and ranging throughout temperate Australian waters. In upper Spencer Gulf, South Australia, more than 200 000 gather annually from May to August to spawn on a shallow reef. Two groups of offspring are produced: fast growers that spawn in their first year; and slow growers that only spawn at a large size when two years old. The reasons behind this unique aggregation, and the significance of the dual spawning pattern, are still uncertain.[27]



Giant cuttlefish, which can weigh up to 5 kg, gather in huge numbers to breed in upper Spencer Gulf, South Australia. Photo: Graham Edgar.

Plant–animal interactions

Australia contains many intricate examples of plants and animals that have evolved together with interactions that require detective work to unravel. For example, many insects (flies, wasps, thrips and scale insects) cause excessive growth of plant tissues called galls, often in association with fungi and other dependent organisms. The insect causing the gall uses the structure to shelter its young from heat and dry conditions. In particular, flies of the family Fergusoninidae have a symbiotic relationship with nematode worms.[28] Female flies carry the nematodes around in their abdomens, and deposit nematodes with their eggs in eucalypt flowers, leaves and stems. The nematodes feed on the plant tissue and form the gall on which the fly larvae feed. When mature, the female nematodes migrate back into female fly larvae. On emergence from the gall, the female flies

A gall of Fergusonina *growing on red stringybark,* Eucalyptus macrorhyncha*, Canberra, Australian Capital Territory. The gall is a microcosm of complex interactions among the life histories of flies, nematodes and plants. Photo: Michaela Purcell, ANU/CSIRO.*

then carry a new generation of nematode larvae to lay with their eggs. The flies are specific to the particular host eucalypt and even to the leaf, flower or stem of the host species.

CONCLUSION

There is still a huge amount of scientific work to be done on the complex evolutionary history and ecology of Australia's biodiversity. Australia has many unique elements to its biodiversity relative to that found elsewhere in the world, but also has much in common with other places, particularly our nearest northern neighbours. This chapter demonstrates that understanding of Australian biodiversity helps develop deeper appreciation of the living organisms with which we share our continent and its marine waters. For us this is a passion, as scientists and authors, but it is also imperative for guiding future management. The chapters that follow will probe further the intricacies of our biodiversity, the challenges it faces in a modern world, and the work being done to help ensure its future.

FURTHER READING

Australian Biological Resources Study (1999) *Flora of Australia. Volume 1*. 2nd edn. CSIRO Publishing, Melbourne.

Butler A, Rees T, Beesley P, Bax N (2010) Marine biodiversity in the Australian region. *PLoS ONE* **5**, e11831. doi:10.1371/journal.pone.0011831.

Cogger HG (2000) *Reptiles and Amphibians of Australia*. 6th edn. Reed New Holland, Sydney.

CSIRO Division of Entomology (1991) *The Insects of Australia: A Textbook for Students and Research Workers*. 2nd edn. Melbourne University Press, Melbourne.

Olsen P, Joseph L (2011) *Stray Feathers: Reflections on the Structure, Behaviour and Evolution of Birds*. CSIRO Publishing, Melbourne.

Van Dyck S, Strahan R (2008) *The Mammals of Australia*. 3rd edn. New Holland Publishers, Sydney.

Australia's biodiversity: status and trends

David K. Yeates, Daniel J. Metcalfe, David A. Westcott and Alan Butler

Key messages

- Australia's biodiversity has been modified since human settlement by land clearing, habitat fragmentation, biological invasions, burning, harvesting of species from land and sea, and climate change.
- There are surprisingly few scientific data sets on how Australian biodiversity is faring; however, direct measures, such as numbers of extinct and endangered species, and indirect measures, such as extent of vegetation cover, show that biodiversity in both terrestrial and aquatic environments is declining. Our marine environments are in good condition, except near cities.
- Ecosystems near large population centres and on prime agricultural land have experienced the greatest declines; hence, most endangered species occur along the eastern coastline and in south-eastern and south-western Australia.
- Evidence from monitoring suggests that pressures on Australian biodiversity are increasing, despite the investments in management.
- Better monitoring of biodiversity is needed to boost the efficiency and effectiveness of management.

HOW IS OUR BIODIVERSITY DOING?

Australia's biodiversity has been modified since human settlement, both Indigenous and European, by burning, land clearing, agriculture, habitat fragmentation, the spread of non-native invasive species, and the harvesting of species from land and sea. These continuing pressures are now being joined by climate change.

Scientists refer to biodiversity 'status and trends'. The status of biodiversity refers to its condition at one point in time. As explained in Chapter 1, biodiversity is difficult to quantify and so any single measure is likely to be inadequate at some level of organisation or spatial scale. Scientists studying a region's biodiversity typically attempt to characterise species richness (the number of species – the simplest and commonest measure) and species diversity (a measure that reflects both the number of species and their relative abundance). These same measures can be calculated equivalently for the other two levels of biodiversity: genes and ecosystems.

Trends in biodiversity can be estimated by comparing measures of richness, diversity, or habitat condition across two or more time periods. Measures have to be able to detect long-term trends, often against a background of short-term variation, such as seasonal change. Future states can be predicted by coupling the past trend with knowledge of the strength and effect of the processes that may continue to modify biodiversity.

Many of us remember patches of vegetation from our childhood being replaced by suburbs or, as in Chapter 1, recall that the fishing in favourite locations seemed to be better when we were children. However, worryingly few scientific data sets are available to assess status and trends of biodiversity in Australia. Scientists are actively seeking accurate, consistent and meaningful measures. This chapter outlines our present knowledge and ideas for improving such monitoring.

WHAT DO WE KNOW, AND HOW DO WE KNOW IT?

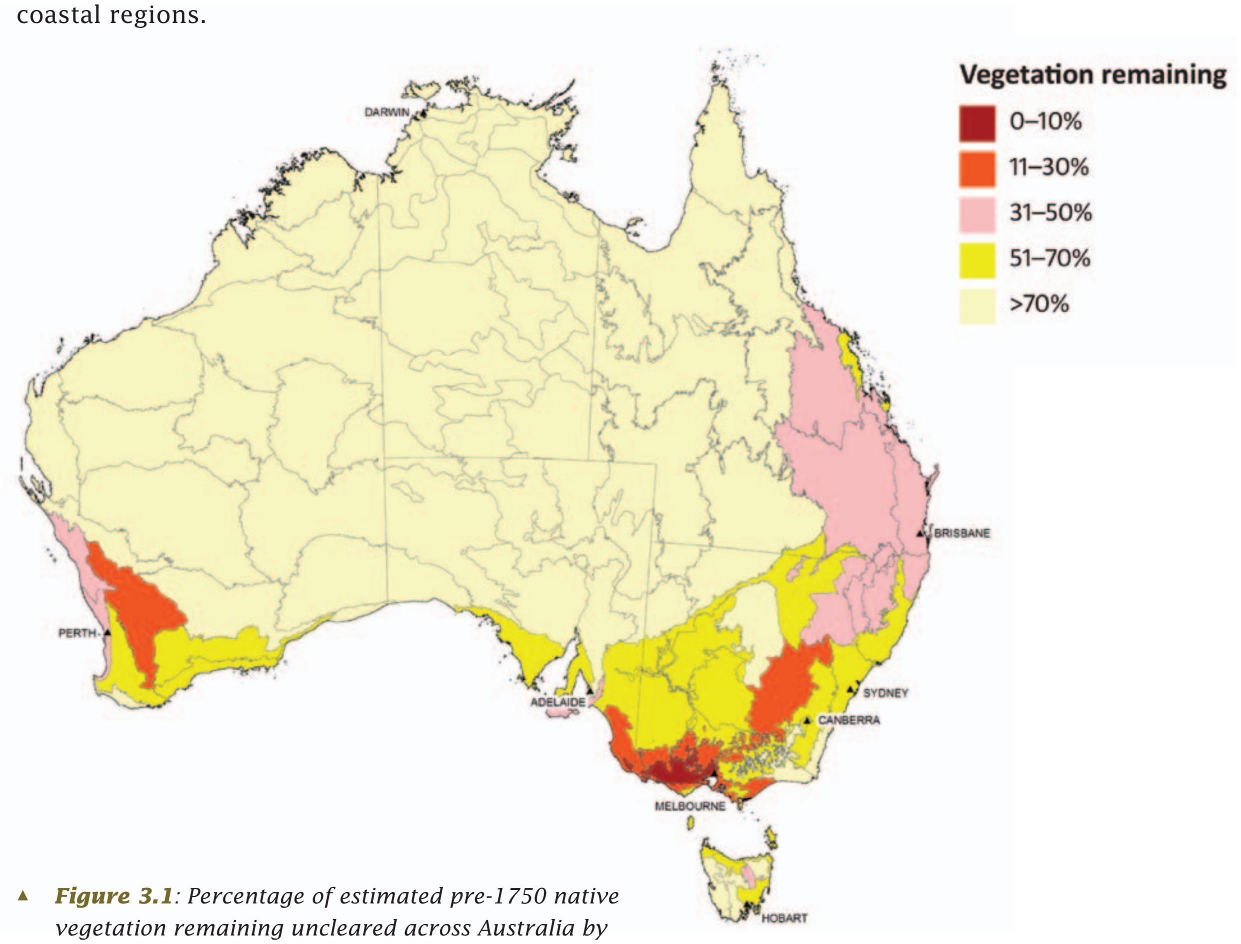
Australian ecosystems

Australia certainly is 'the lucky country'. We still have more relatively unaltered nature per head of population than any other country. Staring out from an aeroplane's window seat for hours on the way to Asia and beyond (the only chance many of us get to view much of our country) we see endless expanses of apparently undisturbed territory. Should we be concerned?

The short answer is – a qualified yes. The greatest clearing of native vegetation since European settlement has occurred in coastal zones adjacent to cities, in the Murray–Darling Basin, and in the wheat belt of Western Australia. Grassy woodlands in the east have been transformed to a remnant of their former selves, with southern eucalyptus woodlands being the most affected.[1]

In these regions much of the remaining native vegetation, including the remnants in agricultural landscapes, is confined to poorer soils in rocky country or in areas of low rainfall, as these have little agricultural value. On the other hand, large tracts of Australia away from the east coast have more than 70% of vegetation still remaining.

The Australian Government has developed a map of Australia broken down into 89 areas called bioregions, each consisting of several interrelated habitats.[2] Those bioregions along the east coast from Queensland to South Australia and in south-west Western Australia have lost more than 50% of their pre-1750 vegetation (Figure 3.1). Marine communities are generally in good condition by global standards, although there are areas of concern on the Great Barrier Reef and some other coastal regions.



▲ ***Figure 3.1****: Percentage of estimated pre-1750 native vegetation remaining uncleared across Australia by bioregion. Note that vegetation may be changed by grazing or altered fire regimes even if it remains uncleared.*[2]

Until 2000, land clearing for cropping in Australia was subsidised, and sometimes obligatory, at rates often exceeding 1 million ha a year. Much of the old-growth forest and woodland has been harvested. Since 2000, land-clearing has slowed dramatically due to legislative changes. Forest regrowth is now outstripping native forest clearing, although the regrowth may not have the same environmental value as the original vegetation.[3]

Broad-scale estimates are useful for reporting, but they obscure details about the state of biodiversity even when there is intact cover. Over 60% of Australia has been grazed by livestock, in many areas to the extent that the soil is degraded and the native herb layer is gone or made up of introduced plants.[3] Grazing by stock and feral animals causes losses of biodiversity not captured by measures of native tree cover. Considerable numbers of non-native species are now altering Australian ecosystems, including more than 3000 plants and 83 vertebrates, and many more invertebrate and marine non-natives.

Canefields adjacent to lowland rainforest, showing the change in land use following clearing. Photo: Dan Metcalfe, CSIRO.

Australia's vegetation types are estimated as declining in quality in State of Environment reports produced by the Australian and state governments, the major cause being increased fragmentation of habitat. Habitat fragmentation occurs when patches of vegetation become too small to sustain populations or too far apart for animals or plants to move between them. The effects may initially go unnoticed; a few long-lived trees could still be present, but declines in their pollinators and seed dispersers mean the patch of habitat is living on borrowed time.

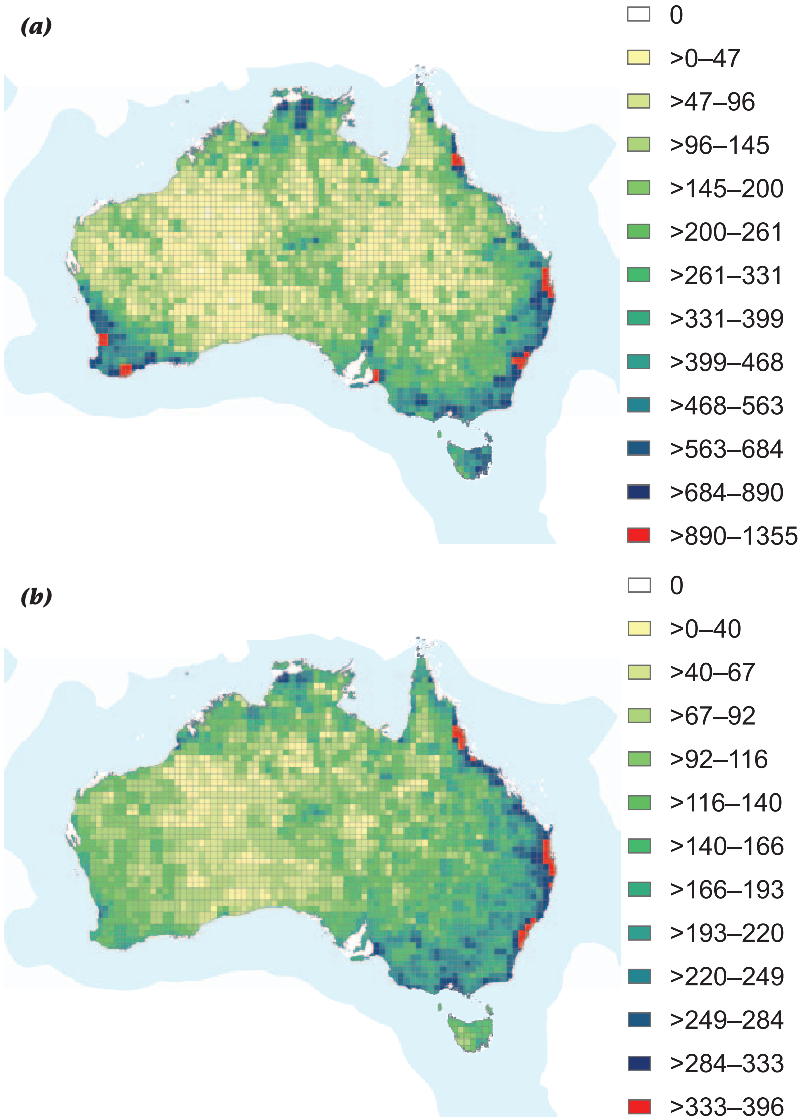
The number and distribution of species

Between 500 000 and 600 000 species of animals and plants currently inhabit the Australian landmass, but only around 25% have been formally named (Table 3.1).[4] Most vertebrate animals and flowering plants have been described. The remaining unnamed 75% are mainly small insects, nematodes, fungi and micro-organisms. Because their diversity and abundance are high they are challenging to measure, so assessments generally use larger organisms, or better-known groups such as ants, as surrogates (or proxies) for trends across all of the species that make up the breadth of biodiversity.

Table 3.1: The numbers of species formally documented by scientists versus the number of species thought to exist in Australia[4]

Group	Number of species described	Number of species estimated to exist	Percentage described
Mammals, birds, reptiles and frogs	2358	2470	95
Fishes	5000	5750	87
Insects	62 000	205 000	30
Other terrestrial invertebrates	52 000	115 000	45
Fungi	11 846	50 000	24
Flowering plants	18 706	21 000	89
Micro-organisms	4186	160 000	2.6

Consolidated databases such as the Australian National Heritage Tool and the *Atlas of Living Australia* have considerably improved understanding of species diversity (Box 3.1). Plants and vertebrate animals are richest along the east coast, in south-western Australia, and in the Top End of the Northern Territory (Figure 3.2). Within these regions, areas of high endemism (the extent to which a species is restricted to a particular area) occur along the central coast of New South Wales, the ranges bordering New South Wales and Queensland, the Wet Tropics around Cairns in north Queensland, and in south-western Australia. It is clear that areas of high species diversity and endemism often overlap with areas of intense land use for agriculture and urban development.



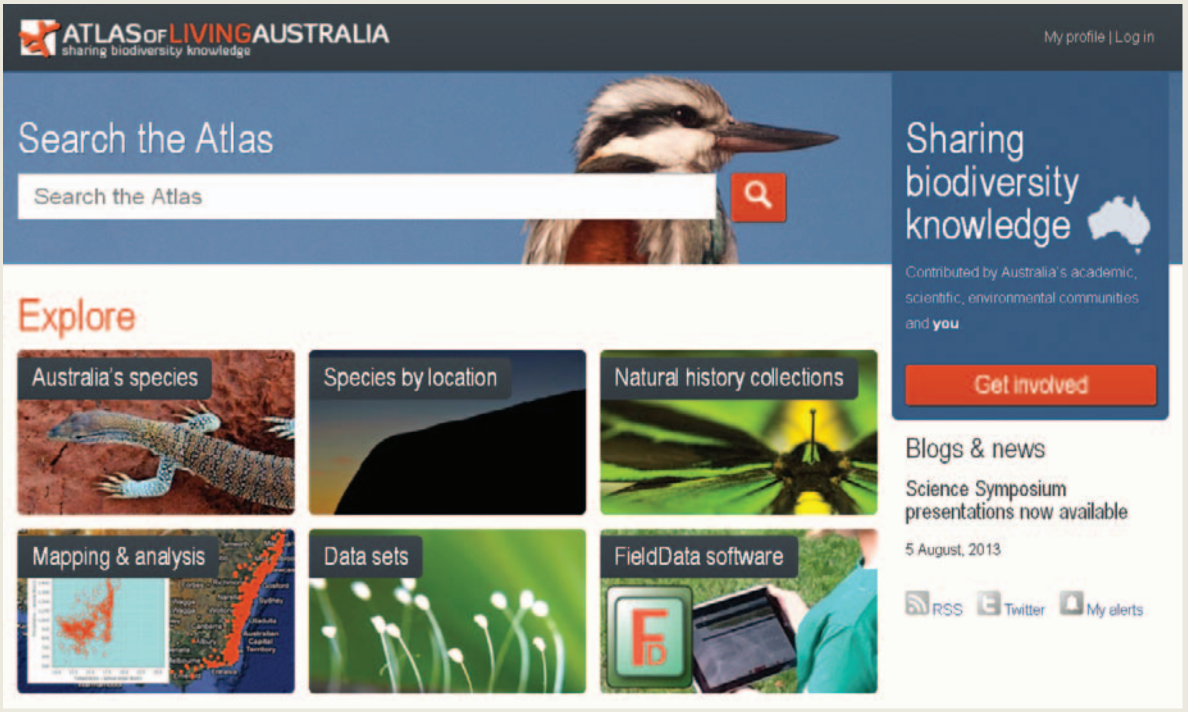
▲ ***Figure 3.2***: *Patterns of species richness for Australian* ***(a)*** *plants, and* ***(b)*** *birds; the higher the number, the more different species there are in that location.*[3]

Box 3.1: Explore Australia's biodiversity and predict future trends

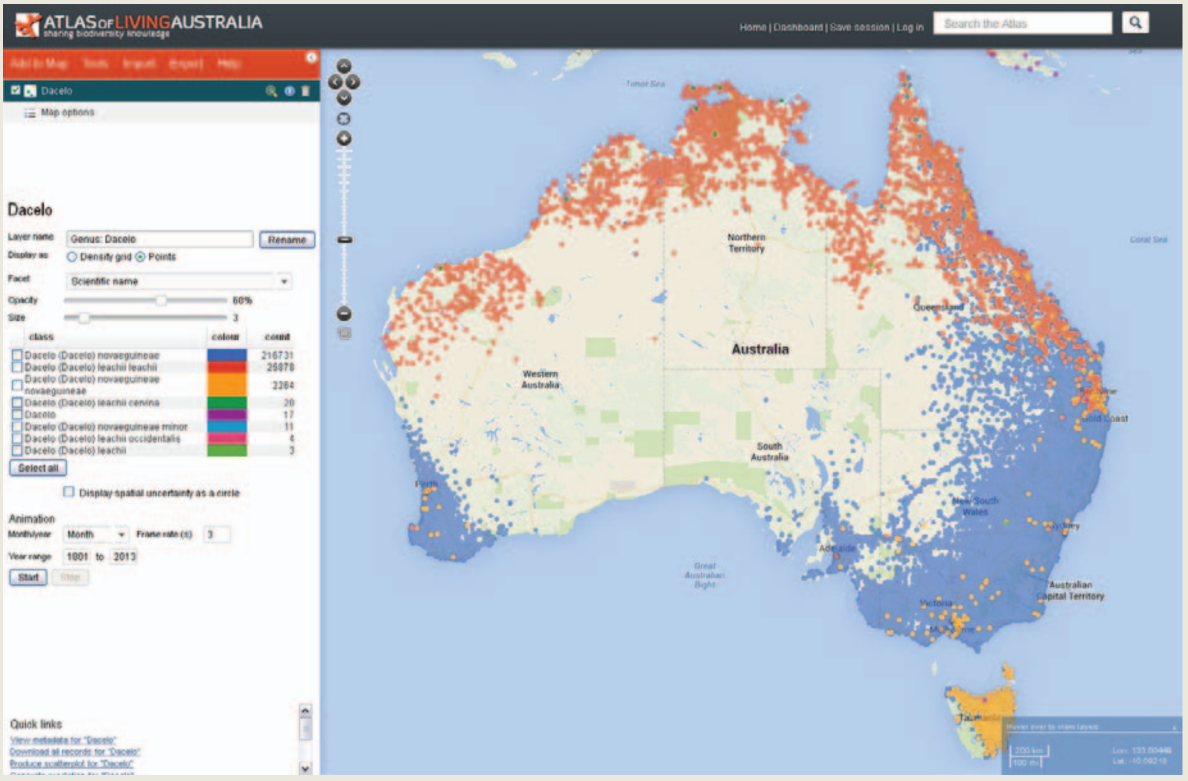
Information on location and conservation status of Australia's species, and tools to predict future trends, are in demand by scientists, decision-makers and community groups. In the past this information on Australia's biodiversity has been difficult to access and analyse as it has been fragmented across biological collections, institutions and government agencies.

The *Atlas of Living Australia* (www.ala.org.au) integrates and mobilises the country's biodiversity information, providing all Australians with free online access to a vast repository of information about Australia's plants and animals (Figure 3.3). The 40 million records in the *Atlas* span species occurrence records, images, molecular data, literature, maps and sound recordings. The *Atlas* is the most comprehensive and accessible data set on Australia's biodiversity ever produced. 'Citizen scientists' can also upload species sightings and photos to the *Atlas*, making these data, which would not normally be captured, available to the scientific community for further study.

The *Atlas* also features mapping and analysis tools to provide information about future trends. For example, the *Atlas* can be used to find out the climatic range of a species based on its current distribution (Figure 3.4), allowing predictions to be made about an animal's response to climate change, or whether a tree might be suitable for revegetation at a particular site.



▲ ***Figure 3.3****: The* Atlas of Living Australia *website provides access to a vast repository of information about Australia's biodiversity.*[5]

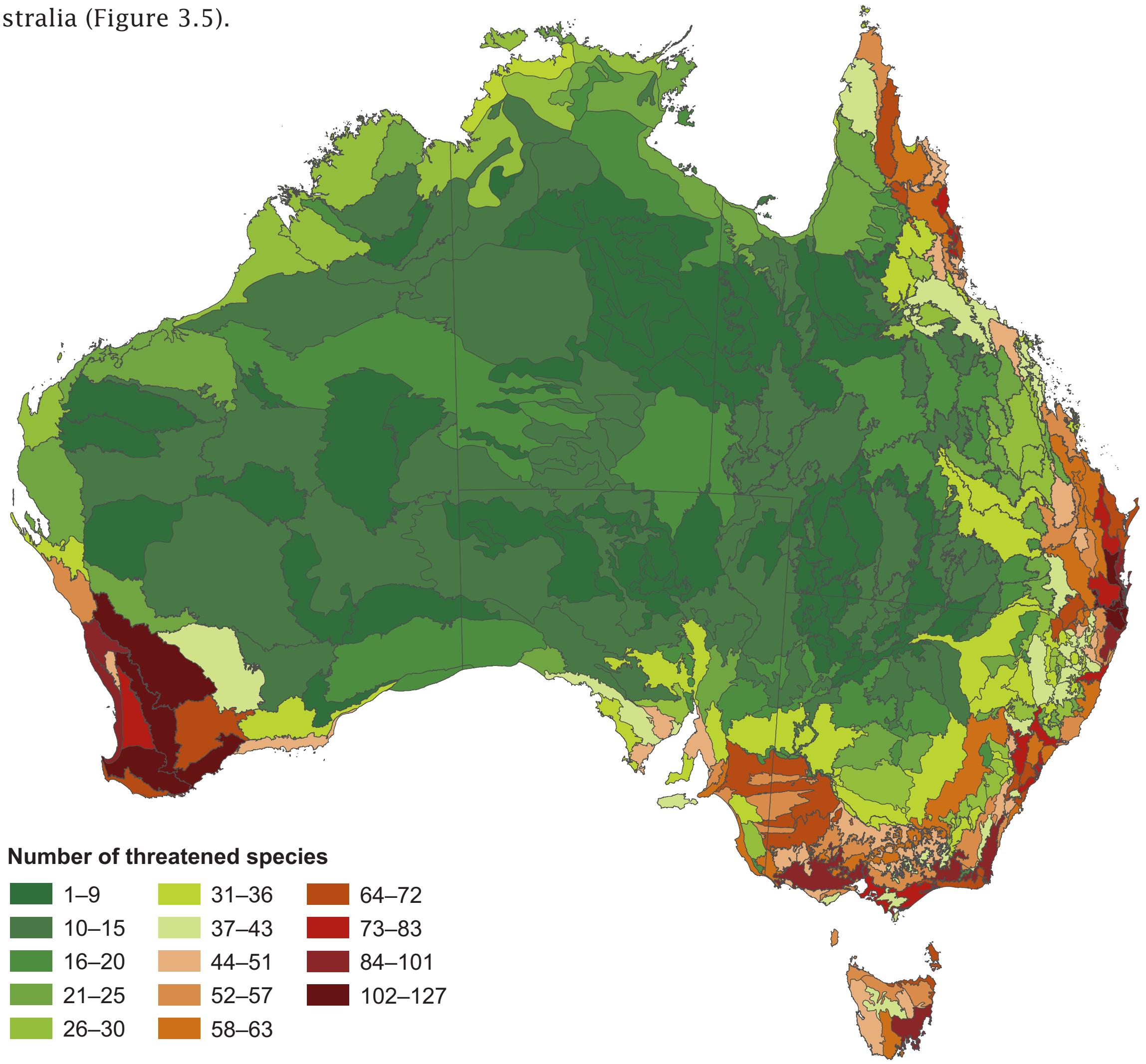


▲ ***Figure 3.4****: A map showing the distribution of two species of kookaburras across Australia.*[5]

Rare, threatened and extinct species

Nearly 100 species of Australian organisms have become extinct since European settlement.[3] Twenty-six of these are mammals, such as the Tasmanian tiger; they account for 30% of the world's mammalian extinctions in the last few hundred years. Given that only 25% of Australia's organisms have been formally identified, and that rare species are hard to find, it is likely that additional extinctions have gone unnoticed.

All Australian states and territories, and the Commonwealth (under the *Environment Protection and Biodiversity Conservation Act 1999*) have formal processes for categorising terrestrial species according to extinction risk. The categories of risk are: of least concern, common, rare, vulnerable, endangered or extinct. Assessment of risk is based on scientific criteria on abundance and trend in their populations. Of the 1600 Australian species of plants and animals classified as rare or endangered, most are concentrated along the eastern seaboard and in southern and south-western Australia (Figure 3.5).



▲ ***Figure 3.5***: *The number of species by bioregion across Australia currently listed as threatened (here meaning that they are rare, vulnerable, or endangered, but not yet extinct) under the* Environment Protection and Biodiversity Conservation Act 1999.[6]

Extinct Australian mammals and birds: ***(a)*** *pig-footed bandicoot,* Chaeropus ecaudatus*,* ***(b)*** *crescent nailtail wallaby,* Onychogalea lunata*,* ***(c)*** *paradise parrot,* Psephotus pulcherrimus*, and* ***(d)*** *Phillip Island parrot,* Nestor productus*. Source: Australian Museum.*

For plants, 25% of species in the best surveyed regions are rare, endangered or vulnerable. Victoria, with the most reliable records, has 49 species considered extinct, and 1826 (58%) species either rare, endangered, vulnerable, or under assessment. The number of rare, endangered or vulnerable plant species per state is correlated with the proportion of naturalised non-native plants because the land clearing, fragmentation and fire that cause loss of native species also allow weeds to spread, including those that can transform communities (Table 3.2).

Threatened Australian plants and animals. ***(a)*** *Hill zieria,* Zieria collina; ***(b)*** *bridled nailtail wallabies,* Onychogalea fraenata*; and* ***(c)*** *the Lord Howe Island stick-insect,* Dryococelus australis. *Photos: (a) Murray Fagg, Australian National Botanic Gardens, (b) W. Lawler, Australian Wildlife Conservancy, and (c) Rohan Cleave, Melbourne Zoo.*

Table 3.2: Proportions of rare and threatened plant species, and of non-native species, among Australian states and territories

State or territory	Total native species	Number of rare, endangered or vulnerable species (and as % of total native species)	Number of naturalised non-native species (and as % of native species)
QLD[7]	8344	202 (2)	1191 (14)
NSW[8]	6152	609 (10)	1665 (27)
VIC[9]	4418	348 (8)	1158 (26)
SA[10]	3400	828 (24)	1400 (41)
NT[11]	4183	65 (2)	455 (11)
TAS[12]	2498	500 (20)	716 (29)
WA[13]	12 257	405 (3)	1050 (9)

Table 3.3: Reductions in the ranges of selected Australian mammals, from Lindenmayer[14]

Mammal	Historic range (km^2)	Current range (km^2)	Reduction (%)
Banded hare-wallaby	490 000	600	> 99
Burrowing bettong	4 370 000	600	> 99
Greater stick-nest rat	1 325 000	600	> 99
Rufous hare-wallaby	1 962 000	1215	> 99
Bridled nailtail wallaby	1 100 000	10 000	99
Long-tailed dunnart	1 175 000	15 500	99
Northern hairy-nosed wombat	106 000	1500	99
Brush-tailed bettong	1 772 000	53 500	97
Hastings river rat	270 000	7500	97
Numbat	1 925 000	59 000	97
Dusky hopping mouse	900 000	42 500	95
Heath rat	236 000	15 000	94
Smoky mouse	151 000	12 700	92
Tasmanian bettong	512 000	48 000	91
Dibbler	99 000	10 300	90
Leadbeater’s possum	44 000	5200	88
Red-tailed phascogale	176 000	29 000	84
Greater bilby	5 296 000	946 000	82

The number of sightings of many woodland birds has declined between 11 and 51% over the past two decades.[14] Numbers of eastern Australian waterbirds in general, and some resident shorebirds in particular, have also fallen significantly.[15] Many Australian rare and threatened mammal species appear to be trending towards extinction, with their original ranges (the geographical area within which the species can be found) reduced between 80 and 99% since European settlement (Table 3.3), and remaining populations are often low in density and more fragmented.

Aquatic and marine environments

In southern Australia, where water has been extracted for agricultural or urban use and natural river flows have been altered, significant biodiversity declines have been a consequence. In the Murray–Darling Basin, there has been a 90% reduction in the area of wetlands. Native fish are found in only 43% of the rivers where they should occur.[3] For much of northern and remote inland Australia, such as the Lake Eyre Basin, watercourses are unaffected by water extraction so ecosystems may remain relatively intact, though there is limited monitoring to allow estimation of biodiversity trends. To assist with these challenges the recent *Groundwater Dependent Ecosystems Atlas* helps managers determine which aquatic ecosystems are linked, and how impacts might be minimised throughout a catchment.[16]

Generally, the condition of the marine environment appears good.[3] However, near-shore marine areas adjacent to large population centres have experienced significant impacts. Some large marine species in Australian waters – Australian sea lions, southern bluefin tuna and the whale shark – were harvested heavily earlier in our history, but despite protection show no signs of recovery. The numbers of turtles, dugongs and coastal dolphins have also declined since European settlement. On the positive side, no-take areas, together with controls on catch, are leading to the recovery of some reef fishes, such as coral trout, that were threatened by over-fishing.

The climate is changing. In coming decades it is likely that sea levels will rise; extreme weather events are expected to increase in incidence and severity, ocean acidification to increase and ocean currents to change. To accommodate these changes, different organisms will evolve and shift in distribution in different ways, and so the composition and dynamics of ecosystems will also change. Along the south-eastern coast, some species of macroalgae, microalgae, zooplankton, invertebrates and many fish are already extending their ranges southward. The Great Barrier Reef is particularly vulnerable to climate change, with declining water quality from catchment run-off and coastal development, fishing, and poaching compounding the effects (Box 3.2).[17] Coral bleaching, due to the symbiotic microalgae leaving the coral under conditions of higher water temperatures, has become more frequent as the ocean warms.[18] Under such conditions, information on both status and trend is vital for effective management.

(a) *Southern bluefin tuna and* ***(b)*** *a whale shark, two species affected by heavy harvesting.*
Photo: (a) CSIRO, (b) Wayne Osborne.

A satellite image showing a flood plume as sediment flows from the Burdekin River, Queensland, out towards the Great Barrier Reef. Photo: NASA, GeoScience Australia, CSIRO.

Box 3.2: Crown-of-thorns starfish

Crown-of-thorns starfish, *Acanthaster planci*, occur naturally throughout the Indo-Pacific region.[19] They are a normal part of healthy reefs. Occasionally, though, they have devastating population outbreaks. Scientists estimate that coral cover on the Great Barrier Reef has halved over the past 27 years, due at least partly to starfish.

Each female starfish produces millions of larvae. Most do not survive; but increased water nutrients, such as from flooding linked to agricultural run-off, can fuel an increase in their food supply of phytoplankton. A small increase in the survival of larvae can produce a huge increase in starfish numbers.

Once an outbreak has begun it can propagate to new reefs not exposed to high nutrient levels – the starfish move southward on ocean currents over about a 15-year period. Reefs can recover over 10–20 years, but additional stresses, such as coral bleaching or cyclones, can delay recovery. Reducing agricultural run-off and therefore nutrient inputs to reef waters is thought to be the best means of control, and so oceanographic models are being developed to provide snapshots of the impacts of flooding.

The crown-of-thorns starfish illustrates the interdependence of ecosystems with the surrounding social and economic systems. Decisions made by farmers regarding fertiliser application can indirectly influence the reefs and the fishing and tourist industries that depend on them.

MONITORING FOR BIODIVERSITY STATUS AND TRENDS

Effective management requires rigorous understanding of the status and trends of biodiversity. This in turn rests upon our ability to monitor biodiversity through time.[20] Monitoring can be effective in two ways: as a routine surveillance activity to assess overall change; or targeted to evaluate the performance of particular interventions. Monitoring underpins the implementation of the *Environment Protection and Biodiversity Conservation Act* by triggering listing of a species or ecosystem as threatened, or de-listing. It is also identified as a priority in the State of the Environment Report[3] and in the National Biodiversity Strategy.[21] Unsurprisingly, disagreement about how to manage is caused by disagreement about what the poor-quality monitoring data are actually telling us.

Despite its importance, however, little effective ecological monitoring is conducted in Australia. Among the relatively successful efforts is the use of diversity of vegetation cover as a surrogate for ecological condition, but monitoring usually requires on-ground visits to many sites. Meeting such requirements is time-consuming and expensive (Box 3.3).

So far, monitoring in Australia can be more accurately characterised as a series of independent local studies, and many programs suffer from poor design, inadequate funding or a failure to contribute to management or policy.[22] Australia has had some successful long-term monitoring programs across national parks. Many local programs have also assessed status and trends of species or ecosystems, or the intensity of threats, and successfully incorporated results into management. Species-based programs have been successful for the eastern bristlebird in New South Wales and the red-tailed black cockatoo in Victoria and South Australia. The most comprehensive national program is perhaps the *Atlas of Bird Life Australia*. Coordinated volunteers collect millions of records, providing a long-term picture of abundance and distribution of birds across the continent.

Given multiple demands on resources, the reasons for monitoring must be compelling. The information must provide insight into threats and allow management to assess the effectiveness of its actions. Even when good monitoring programs are in place, timely responses may be lacking, as occurred in the recent extinction of a bat, the Christmas Island pipistrelle, *Pipistrellus murrayi*.

Scientists are striving to design more cost-effective and coordinated monitoring programs at larger scales. The Terrestrial Ecosystems Research Network's recently established long-term ecological monitoring sites across Australia, based on a common set of methods, infrastructure and data management, and a commitment to make the information publicly available, is a step in this direction.[23] Similar marine programs exist, run by the Australian Institute of Marine Science on the Great Barrier Reef.

The issues confronting Australian biodiversity require sampling far more broadly than at present, and new cost-efficient technologies such as sensor networks and metagenomics (see Chapters 9 and 10). We need monitoring activities at local and national scales, and an agency

Box 3.3: National Flying-fox Monitoring Program

Australians have an ambivalent relationship with flying-foxes. Concern is focused on the impact of flying-foxes on agriculture as well as noise, smell and diseases from urban camps. Concern about population declines led to the listing of the grey-headed and spectacled flying-foxes, *Pteropus poliocephalus* and *P. conspicillatus*, as threatened. A conflict of values means that decisions about flying-foxes are invariably contested, the debate not being helped by a lack of scientific information. The National Flying-Fox Monitoring Program was established in 2012 to establish population trends through time.[24]

Flying-foxes are hard to monitor because they are highly mobile, regularly moving tens to hundreds of kilometres in short periods and clocking up thousands of kilometres over weeks. The monitoring program has been designed to account for these movements. With the help of volunteers, roughly 500 camps over 3500 km between Adelaide, South Australia, and Cooktown, in far north Queensland, are visited within the same period each quarter, with each monitoring event completed in just three days. This minimises the possibility of missing or double-counting parts of the population.

It has been estimated that because of natural year-to-year variation in population size, 14 years of data will be required to identify any human-induced change with statistical confidence.[24]

Monitoring even just a couple of species, such as these flying-foxes, can be a time-consuming and expensive process. Photo: David Westcott, CSIRO.

to take responsibility for the storage, management and accessibility of those data. The recent development of the National Plan for Environmental Information, which aims to boost connections between monitoring effort and Australian Government policies and programs, is a vital step in this direction.[25]

A CSIRO technician installing meteorological instruments on top of a 75 m tower, which forms part of the Terrestrial Ecosystem Research Network's OzFlux Facility. The Facility is a network of towers across Australia that continuously measures the exchanges (flux) of carbon dioxide, water vapour and energy between terrestrial ecosystems and the atmosphere. It is an example of long-term, large-scale monitoring that is helping inform Australian biodiversity management. Photo: Gregory Heath, CSIRO.

CONCLUSION

The main pressures on Australia's biodiversity – habitat fragmentation, altered fire regimes, invasive species (both non-native and native), harvesting of species, and climate change – are increasing, and the rate of species decline is not slowing down. Australia continues to set itself challenging targets. The *Australian Biodiversity Conservation Strategy (2010–2030)*[21] aims to increase the area managed for conservation by 600 000 km^2. To achieve these targets an effective long-term monitoring program is required. The management and scientific challenges may be large, but so too will be the environmental and social benefits.

Drawing on international activities will also support our national effort. A global system of biodiversity observation networks called GEOBON was started in 2008 for detection of change using both on-site measurements and remote sensing techniques.[26] The Intergovernmental Platform on Biodiversity and Ecosystem Services, established in 2012, also aims to provide an independent, scientifically sound, uniform and consistent framework to enable scientific knowledge on biodiversity to be translated into policy action. Australia is well placed to benefit from such global initiatives in responding effectively to the challenge of biodiversity decline.

FURTHER READING

Australian Government Department of Environment and Water Resources (2007) *Australia's Native Vegetation: A Summary of Australia's Major Vegetation Groups*. <http://www.environment.gov.au/erin/nvis/publications/major-veg-summary.html>.

Birdlife Australia (2008) *State of Australia's Birds*. <http://birdlife.org.au>.

Chapman AD (2009) *Numbers of Living Species in Australia and the World*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra. <http://www.environment.gov.au/node/13875>.

Lindenmayer D (2007) *On Borrowed Time: Australia's Environmental Crisis and What We Must Do About It*. Penguin Books Australia, Melbourne.

Tools for managing and restoring biodiversity

Tara G. Martin, Josie Carwardine, Linda Broadhurst, Simon Ferrier, Craig James, Andy Sheppard, Stuart Whitten and Iadine Chades

Key messages

- The challenge of managing and restoring biodiversity is being met with a multitude of tools and approaches for developing and improving decision-making and on-ground actions.
- Plans for managing biodiversity have to be formulated in the context of constrained resources, imperfect knowledge and likely conflicts between value sets.
- Land managers now have a toolbox of potential actions to choose from, depending on the threat and its scale: implementation of conservation reserves; control of invasive species; restoration of degraded ecosystems; and last-resort translocation or captive breeding of endangered plants and animals.
- Decision tools allow the best choices to be identified: what management actions should be taken, when and where, given competing societal values, economic constraints and scientific uncertainty.

INTRODUCTION

Managers of biodiversity face future uncertainty, with limited resources and competing values hindering timely responses.[1] Even with ample funds, it is often still unclear what management action will give the best chance of recovering biodiversity. This uncertainty has many causes: being unsure how many individuals of an endangered species exist; the condition or extent of habitats; the likelihood of success of management actions or their political and social feasibility; and the influence of emerging threats such as climate change. This chapter turns attention to the tools of biodiversity protection and restoration, and the improved decision-making demanded for effective management. We first discuss the actions that are now available to arrest declines, and then we illustrate ways to make sound choices between management actions. The next chapter deals in greater detail with one particularly important strategy for biodiversity management – Australia's system of protected areas.

ACTIONS TO MANAGE THREATS

There are two leading threats to Australia's biodiversity. The first is the loss and fragmentation of native habitat as a result of agricultural expansion and urban and industrial development, and the second is the impact of invasive species, particularly non-native. Other threats include over-grazing, altered fire regimes, over-harvesting, water pollution, disease (Table 4.1) and climate change (Table 4.2).

Habitat protection and restoration

Clearing of ecosystems over the last 220 years, and the resultant fragmentation of forests, woodlands, savannas and grasslands, is responsible for the status of many threatened and endangered plants and animals.[2,3] The establishment of state and Commonwealth legislation concerning broad-scale clearing of native vegetation has reduced the rate of vegetation loss, although widespread clearing of regrowth continues. Mitigation of these effects takes two forms: protecting existing ecosystems and restoring them (Table 4.1).

Habitat restoration activities are gaining pace both passively (allowing native species to repopulate in their own time) and actively (seeding, planting and translocation). Plant growth can be enhanced through inoculation of roots with nitrogen-fixing bacteria; likewise, bacterial inoculation encourages beneficial mycorrhizal fungi.[4] Elevated nutrient levels caused by agriculture constrain restoration in many Australian ecosystems by promoting rapid growth of non-native plants that out-compete natives.[5] Use of particular native plants, and other soil treatments, can reduce nutrient levels.[6]

Table 4.1: Major threats to Australian biodiversity and management actions to abate them

Threat	Management actions
Habitat loss and fragmentation	Halting clearing of native vegetation via legislation Expanding the National Reserve System (see Chapter 5) Protection and restoration of native vegetation on private land through incentives Restoration via native revegetation, and inoculation of soil with beneficial micro-organisms Passive natural rehabilitation via fire and grazing management Captive breeding and translocation
Invasion by non-native species	Preventing introductions via regulation and quarantine Surveillance, detection and eradication of new arrivals Containment of slow-spreading species Controlling existing invaders by pesticides or herbicides, baiting, and culling Protection of ecosystems and species by removal (plants) or fences (feral predators and herbivores), or moving at-risk species to islands Biological control
Livestock grazing	Management of grazing (stocking rate and access to water) Protecting vulnerable species or ecosystems by fencing Spelling areas from grazing to allow recovery
Altered fire regimes	Instigation of less intense, smaller fires to create a mosaic of age-since-burn where too frequent and on too broad a scale Controlled burning where fires are too infrequent Suppression of non-native invasive grasses with high fuel load (e.g. gamba grass and buffel grass) or fire-assisted shrubs (e.g. broom)
Over-harvesting of native species	Regulation and anti-poaching enforcement Compensation to offset loss of harvests Captive breeding and reintroduction programs
Water pollution, both marine and fresh water	Regulation of chemical and fertiliser use and dumping of waste Minimising water use in irrigated agriculture Increasing biodegradability of waste Improved sewage treatment and containment
Disease	Lower risk of spread through strategies based on epidemiology Maintain disease-free locations of suitable habitat Quarantine through isolation or destruction of infected individuals to minimise spread Captive breeding and release of disease-free populations

Fertile land has been cleared of native vegetation to make way for agriculture. In some regions, less than 5% of native vegetation remains. Photo: Tara Martin, CSIRO.

Captive breeding and translocation of endangered species are a last resort. A quick decision to augment the captive population of orange-bellied parrots, *Neophema chrysogaster*, narrowly avoided their extinction.[1] Translocation of several small- to medium-sized mammals to enclosures and offshore islands free of predatory cats and foxes has also saved these species from extinction.[7] However, translocation has its challenges because it can lead to conflict among human interests; may have negative consequences for either the target species or the recipient ecosystem; can be costly relative to other actions; and, finally, often fails.[8] Under climate change the challenges will be exacerbated because translocation may need to occur to sites outside historical distributions.[8–10]

Fewer than 100 breeding orange-bellied parrots, Neophema chrysogaster*, remain in the wild. Thanks to prompt action to increase the captive-bred population, extinction may have been avoided.[1] Photo: Chris Tzaros.*

Restoring sufficient genetic resources is fundamental to the sustainability of plant populations and biodiversity in general. Low genetic diversity can lead to inbreeding and decline, widely reported for fragmented plant populations,[11] and insufficient capacity to evolve during environmental change. New gene-sequencing technologies may improve restoration through rapid assessments of the genetic quality of wild and restored populations, highlighting 'hidden' species, and broadening our understanding of adaptation.

Management of non-native invasive species

In the absence of natural enemies or diseases to moderate their abundance, non-native invasive species are expanding in Australia – there are over 800 such plants, 34 fishes, 25 mammals, 20 birds, four reptiles, more than 400 marine pests, and many invertebrate and plant diseases.[12] There are also species regarded as native to Australia that are becoming invasive, but they are still a comparatively minor part of the invasive problem. Management of non-native species involves keeping them out of Australia, containing them if they get in, and controlling them if they escape. Australia puts a major effort into preventing entry. Despite this, such species still arrive and are then often subject to costly eradication. Where eradication is no longer possible, we must learn to live with them and seek to minimise the harm they cause.

The only continent-wide and long-term means of managing an established non-native invasive species is biological control, the introduction of highly specific natural enemies or diseases from the invader's native range. Such control has been successful with many non-native weeds, for example rubber vine, *Cryptostegia grandiflora*, and bridal creeper, *Asparagus asparagoides*, and also for rabbits via myxomatosis and rabbit haemorrhagic disease. The exploration of cyprinid herpesvirus 3 (CyHV-3; formerly known as koi herpesvirus) for the control of carp, *Cyprinus carpio*, in wetlands is among the next generation of promising opportunities.

Predation by feral cats and foxes presents a major threat to Australian wildlife. Management ranges from construction of predator-free enclosures to culling of predators. Photo: Chris Tzaros.

Livestock grazing management

Livestock grazing is the most extensive land use across Australia and has contributed – along with grazing by feral animals – to biodiversity loss through the removal or alteration of native vegetation and degradation of drought refuges (permanent water sources that sustain wildlife during times of low rainfall).[13] Management of grazing through fencing and better distribution of water points is bringing grazing more in tune with variability in climate, and removal of grazing from vulnerable habitats such as the alpine zone and riparian areas will lessen impacts (Table 4.1).

Ecologically sustainable livestock grazing in Queensland. Photo Tara Martin, CSIRO.

Fire management

Much of Australia's vegetation is adapted to periodic burning. Bushfires recur with intervals of a few years to many decades, particularly in northern Australia but also in other parts of the country. Occasional large fires in the eucalypt forests and alpine woodlands of south-eastern Australia would seem at first sight to be bad, but they have no negative long-term impact on the diversity of plants and animals as long as intervals between fires remain long enough for regeneration.[14] In the northern savannas, fires are a frequent occurrence to which the vegetation is generally well adapted, but they have become more frequent, intense and widespread, threatening the persistence of some sensitive species. Here, less intense and less extensive wet-season burns prevent large hot dry-season fires, as long as highly flammable non-native grasses are contained (Table 4.1).

Preventing over-harvesting

Commercial fishing has resulted in diminished populations of many species (e.g. Murray cod, *Maccullochella peelii*; snapper, *Pagrus auratus*; and orange roughy, *Hoplostethus atlanticus*), as has illegal harvesting of molluscs, corals, orchids, birds, reptiles and fishes. Removal of native species that pose a threat to agriculture has also caused decline (e.g. Carnaby's cockatoo, *Calyptorhynchus latirostris*; emu, *Dromaius novaehollandiae*; and spectacled flying-fox, *Pteropus conspicillatus*), and even extinction (thylacine, *Thylacinus cynocephalus*). Actions to reduce over-exploitation include regulation, compensation, and encouragement of captive breeding (Table 4.1).

Box 4.1: Why biodiversity decline and management constitute a 'wicked' problem

The term 'wicked' here means not that the problem is evil, but that it is difficult or impossible to solve.

- The problem resists clear definition – views about it vary among interested people.
- The apparent cause may not be the root of the problem; it may result from interactions among causes.
- Potential solutions may lead to unforeseen consequences – for example, reconnecting remnants of bush may facilitate movement of pests and weeds.
- Problems and solutions change through time – the shifting distributions of invasive species as a result of climate change may create problems or might allow opportunities for control.
- Solutions are socially and organisationally complex – they impose costs on some individuals and benefits on others, and implementation requires coordination among many organisations.
- Solutions involve human behavioural change – the commitment of individuals to consider alternative values and to cooperate is essential.

Pollution control

In freshwater, estuarine and marine environments, pollution is a threat that involves chemicals, run-off of fertiliser and sediment, plastics and nets. Impacts on the Great Barrier Reef have prompted management of agricultural practices and the declaration of reserves and zones on reefs for different forms of commercial use (Box 4.1). The effect of discarded plastic bags on marine turtles has prompted campaigns to reduce their use and to intercept plastics in stormwater (Table 4.1).

Disease management

Phytophthora fungus, *Phytophthora cinnamomi*, and myrtle rust, *Uredo rangelii*, are examples of introduced diseases that affect native ecosystems and threaten the persistence of many plants. Neither can be eradicated: both are managed to minimise spread. Facial tumour disease in Tasmanian devils, and chytrid fungus (*Batrachochytrium dendrobatidis*) in frogs, have led to population declines and possible extinction. Actions to abate impact are diverse, from quarantine of non-infected populations through to treatment or destruction of infected individuals (Table 4.1).

Tasmanian devil, Sarcophilus harrisii, *infected with facial tumour disease. Photo: Menna Jones, University of Tasmania.*

Climate change adaptation

Climate change presents a particular challenge because of the breadth of its impact and its amplification of existing threats (Table 4.2).[15–17] For example, climate change may cause more high risk fire days (i.e. high temperatures and low humidity) and favour the spread of fire-prone non-native invasive grasses.[18] Research predicting future responses to climate of species and ecosystems suggests that management efforts focused on ecological processes, rather than on individual species or habitat patches, are likely to be most effective. The *Atlas of Living Australia* can help inform restoration options under climate change (Box 4.2). From here, there are broadly two pathways: to manage threats while letting biodiversity recover naturally; or to intervene by relocating species or ecosystems.

The tasks summarised in Tables 4.1 and 4.2 are so substantial, so inherently multi-scale and interactive, that resources are inevitably inadequate relative to the size of the challenge. Progress on these 'wicked' problems (Box 4.1) is often stalled due to uncertainty and disagreement on the best course of action.[19]

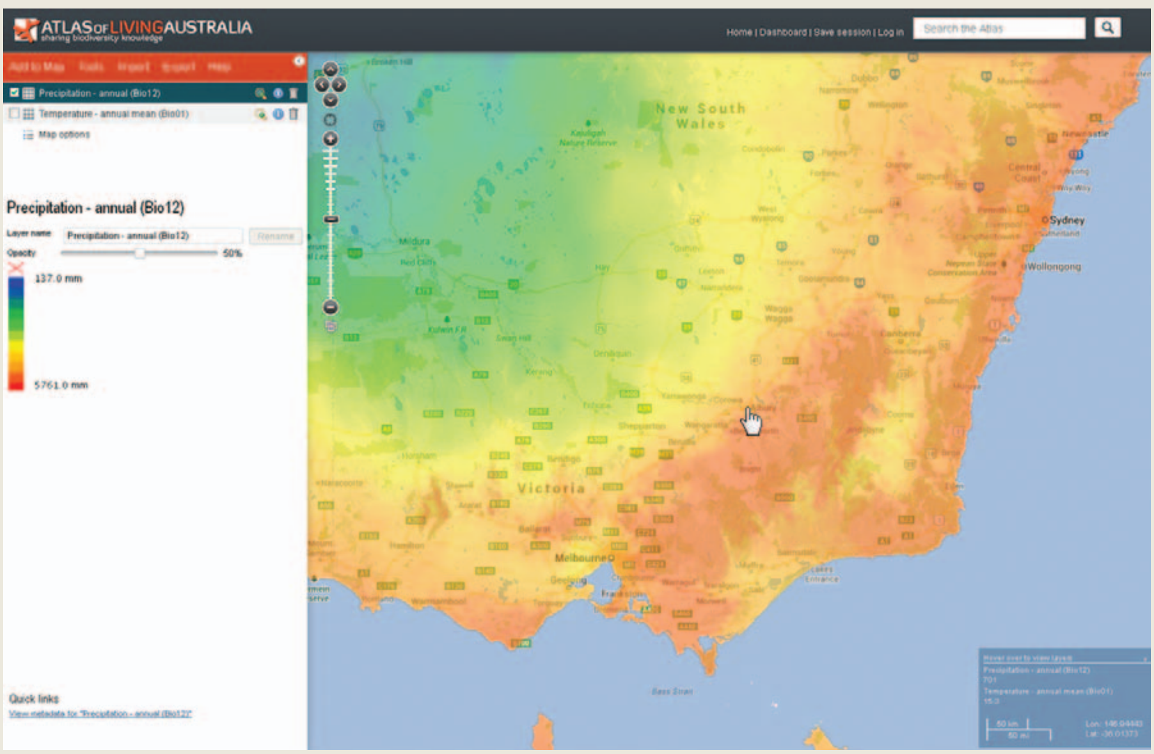
Table 4.2: Management responses to adapt to climate change

Impact on biodiversity	Examples of changed conditions	Examples of management actions
Environmental conditions no longer support species	Too hot, too wet, too dry	Facilitate movement along corridors Assist species to move by relocation Leave species to adapt as best they can
Extreme events damage environment	Large storms, damaging winds, floods	Plan for ecosystem defences (e.g. mangroves protect shoreline ecosystems) Ensure species are distributed in many populations to spread extinction risk associated with catastrophic events Relocate containment facilities for non-native species (zoos, aviaries, fish farms, botanical gardens) from vulnerable areas
Entire ecosystems change	Species disappear and are replaced by others Invasive plants change fire regimes	Identify and manage refuges that buffer species from rapid change Manage to avoid undesirable monocultures
Altered interactions among species	Prey populations escape control by their predators	Encourage novel combinations of species Respond rapidly to pest outbreaks
Ecosystem services change	Natural pest and disease controls break down Pollination disrupted	Manage for services that best equip systems to adapt

Box 4.2: The *Atlas of Living Australia* helps guide revegetation under a changing climate

The challenge of revegetating, rehabilitating and restoring landscapes intensifies in a changing climate because of the need to plant species suitable not just for current but also potential future conditions at a given location. The *Atlas of Living Australia* aids selection of plants that should be least vulnerable to changing environmental conditions at specific sites. The *Atlas* can identify tree, shrub and groundcover plants present in a given area, generate maps of their current distributions across Australia, and help to identify locations where particular plants are already experiencing relatively extreme climatic conditions (Figure 4.1). The *Atlas*'s environmental data layers, featuring soil moisture, bushfire frequency, rainfall and temperature, can be overlayed on the plant's distribution, and using this the range of conditions suitable for each species can be obtained.

The *Atlas* also contains climate change scenarios for 2030, allowing predictions on whether each species would be suited for revegetation at a particular site into the future. This enables sourcing of seed not only of a particular plant species, but also from a particular origin, to optimise future climatic compatibility.



▲ ***Figure 4.1****: Screenshot showing use of the* Atlas of Living Australia*'s mapping tools to determine climatic conditions at a target site, with data layers loaded over an underlying map.*

DECIDING ON MANAGEMENT ACTIONS

Some insights on biodiversity management are starting to emerge. The first is that management goals must be flexible, acknowledging that it may not be possible to return ecosystems to an earlier state following disturbance.[20] For example, restoration efforts may need to abandon long-held use of local seed sources in favour of genetically diverse seed to maximise adaptation under climate change.[21] Second, land clearing and shifts in species distributions are contributing to novel ecosystems. Assumptions of a static environment no longer hold, and it may now be necessary to embrace new possibilities and constraints.[22] Third, management and restoration are often costly. Hence, costs and benefits of an action, along with the social feasibility of undertaking it, must be factored in from the outset.[23,24] Finally, time is often critical.[1]

Failure to act quickly on evidence of rapid population decline led to Australia's most recent mammal extinction, that of the Christmas Island pipistrelle, Pipistrellus murrayi.*[1] Photo: Lindy Lumsden.*

Our ability to decide wisely among available options depends on knowledge of the issue, the various values brought to its consideration, and the surrounding legal constraints (such as land tenure or conservation covenants). How do we decide what threats to manage, what actions to use to manage them, where in the land or seascape to do so, and when? An essential approach to this problem is to use a framework that incorporates multiple competing priorities, imperfect knowledge about the future, and limitation in resources.

Structured decision-making is a framework for deciding between actions. It helps us to understand complex problems by defining alternative options, typically involving several groups of decision-makers.[25] The tools range from relatively simple spreadsheet analyses through to computer-based decision models. A challenging step is to evaluate the possible effectiveness of different management actions (e.g. different habitat restoration techniques or options for reserve design). Research aims to help improve this step by developing better ways of 'scaling up' local benefits of individual actions to predict collective outcomes from alternative sets of actions across ecosystems, regions, or even the entire continent.[26,27]

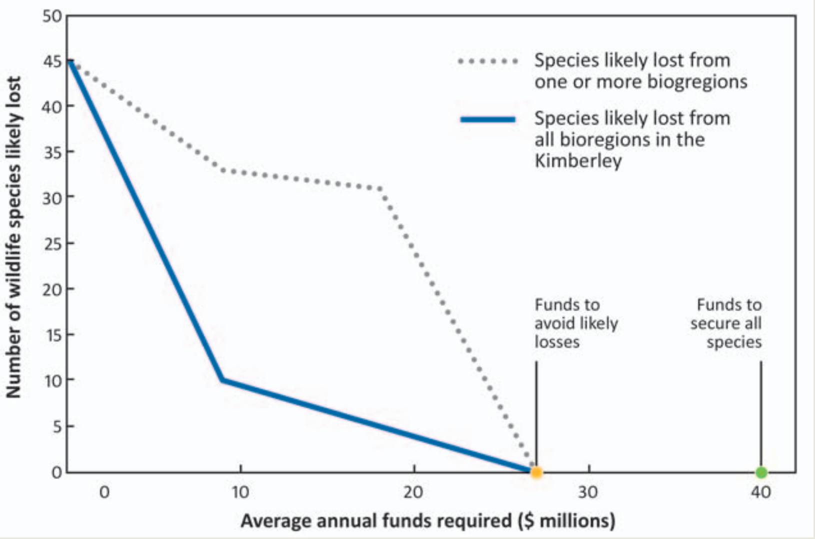
We now turn our attention to three examples of structured approaches to decision-making and how they can help highlight cost-effective management actions. A related example, systematic conservation planning, is highlighted in Chapter 5, which deals with our protected areas.

Prioritising management of threats

Optimising the management of threats requires prioritising on the basis of benefit per dollar spent and likelihood of success. Where likely benefit of management cannot be measured financially, cost-effectiveness analysis of any benefit divided by its cost is a useful tool for enabling more justifiable investments in management.[28] 'Co-benefits' such as improvements to human livelihoods, agriculture or ecosystem services can also be included.[24] Cost-effectiveness analysis is being used to prioritise actions to recover threatened species,[24,29,30] and inform landscape-scale restoration (Box 4.3).[31]

Box 4.3: Cost-effectiveness of management interventions in the Kimberley

State government agencies, Indigenous land councils, the pastoral industry and non-government organisations are responsible for implementation of actions to ensure persistence of the Kimberley's wildlife.[24] The aim was to assess cost-effectiveness of management actions, as measured by the benefits in terms of predicted persistence of 637 vertebrate species over 20 years. The study drew upon field data and the knowledge of 27 experts on the benefits of managing fire, introduced herbivores, weeds and feral cats. The study found that an average of $27 million per year was required to avoid likely losses of wildlife, while an average of $40 million per year would secure all species (i.e. estimated likelihood of persistence greater than 90%) (Figure 4.2).



▸ ***Figure 4.2****: The number of wildlife species predicted to be lost (i.e. chances of persistence estimated to be below 50%) from at least one bioregion (dashed line) and from the entire Kimberley (solid line), at various levels of investment in management.*[24]

Managing endangered and invasive species

Decisions about managing species, be they rare and endangered or a damaging invasive species, reflect two extremes of the same issue. Detecting an invading pest at an early stage and managing an endangered species constitute the same problem of allocating limited resources. In the case of pests you want to know where they first appear, and with rare and endangered animals you need to know when they're no longer around. But many threatened or invasive species are difficult to detect when numbers are low, when an invader first appears or an endangered population is on its last legs. Even large endangered mammals can be surprisingly hard to detect.[32] Consequently, it is possible that effort is invested in management even after the invasive pests, diseases or threatened species have disappeared. Conversley, in the absence of sightings, managers might give up too early. Hence, the manager needs to know when to start or stop work, and where. Using an optimisation technique for making decisions in uncertain circumstances, the best course of action can be determined to solve such problems.[33]

Decision-making under conditions of climate change

The approaches to decision-making outlined here aim to find solutions to current problems. However, decision-making during a period of climate change adds further complexity requiring us to mention several pertinent principles.

Past assumptions will be challenged because change is inevitable. Approaches to management have tended to assume that ecosystems are relatively static, but with climate change there will inevitably be widespread change to ecosystems. Managers may need to think differently about the definitions of 'natural' and 'invasive' species because some native species might end up having undesirable consequences in areas that they invade as the climate changes.[34] Future efforts may need to look beyond idealistic approaches and concentrate on new, more pragmatic options.

Management objectives will change. Should we focus on managing species or ecosystems and, given that not all can be saved, which particular species or ecosystems should be the focus? Societal values and management objectives will change, so plans need to be flexible.

Future landscapes will be designed. It is likely to be preferable to engineer a desirable future landscape rather than allow the processes to run their course towards an unhappy future. Techniques such as relocation of species are likely to be supported socially and scientifically if the alternative is to watch them become extinct.[8]

Decision-making will be complex. Some guidelines help to simplify.

- Actions with long-lived outcomes should be considered most carefully, given uncertainty about the distant future. Planting of long-lived trees requires that they persist for a century or more, but will that species survive in the location 100 years hence?
- Actions that are difficult to reverse should be considered carefully because they reduce options to do other things in future.
- Uncertainty should not prevent decisions; not acting is in itself a decision to be evaluated against other possible decisions.

CONCLUSION

Managing biodiversity requires good decisions in the face of limited money, short time-frames, trade-offs with other societal priorities, and incomplete knowledge. The stakes are often high, the outcomes often have immediate effects upon people, and the trade-offs can be morally and emotionally taxing.[22] The development and refinement of management actions, tools allowing choice among them, and monitoring of their effectiveness can help us navigate these wicked problems. In some cases, solutions will be found and biodiversity protected, whereas in others the best solution may be to stop and instead divert the resources to a problem with a higher likelihood of being solved.[35] Using these tools and the expertise at hand, Australia has a great opportunity to manage and restore its biodiversity values.

FURTHER READING

Balmford A (2012) *Wild Hope: On the Frontlines of Conservation Success*. University of Chicago Press, Chicago.

Carwardine J, O'Connor T, Legge S, Mackey B, Possingham HP, Martin TG (2012) Prioritizing threat management for biodiversity conservation. *Conservation Letters* **5**, 196–204.

Chadès I, Martin TG, Nicol S, Burgman M, Possingham HP, Buckley Y (2011) General rules for managing and surveying networks of pests, diseases and endangered species. *Proceedings of the National Academy of Sciences* **108**, 8323–8328.

Gregory R, Failing L, Harstone M, Long G, McDaniels T, Ohlson D (2012) *Structured Decision Making: A Practical Guide to Environmental Management Choices*. Blackwell Publishing, Oxford.

Martin TG, Nally S, Burbidge A, Arnall S, Garnett ST et al. (2012) Acting fast helps avoids extinction. *Conservation Letters* **5**, 274–280.

Managing Australia's protected areas

Andy Sheppard, Simon Ferrier and Josie Carwardine

Key messages

- Australia's National Reserve System provides a 430 million ha foundation for biodiversity, representing a high proportion of Australia's ecosystems.
- Great progress has been made towards an effective National Reserve System, but work remains to be done before it will grow into a full network allowing species and ecosystems to move across landscapes and seascapes.
- Habitats must be connected in order for native species to persist, and 'connectivity conservation' emphasises management of the land through which plants and animals move around, whether or not the land is part of a formal reserve system.
- Off-reserve management complements the National Reserve System with approaches that include habitat corridors, enhancement of remnant bush, and coordinated management of larger tracts of private and public lands.

INTRODUCTION

Australia is responding to the range of processes that are threatening the integrity of our ecosystems. In the previous chapter we saw an array of different measures that are being employed to manage threats to biodiversity and tools for planning and decision-making to get the best results for our investment. The focus of this chapter is on the backbone of these responses, the Australian protected area network. Australia appears to be well on the way towards achieving globally agreed targets under the Convention on Biological Diversity for the amount of our country covered by protected areas, being 17% of terrestrial ecosystems and inland waters, and 10% of coastal and marine areas, by 2020.[1]

Australia's primary instrument for the protected area network is the National Reserve System (Figure 5.1),[2] initiated after the 1992 Rio Earth Summit that led to the Convention on Biological Diversity.[3] Development of the National Reserve System is guided by a strategy aimed at protecting habitat so that ecosystems and species can persist with minimal management. It comprises both publicly and privately owned elements and is expected soon to cover 430 million ha of marine and terrestrial ecosystems. In public ownership, Australia has some 550 national parks and state conservation areas covering over 28 million ha[4,5] and 22 marine parks which, along with 48 marine reserves, constitutes the largest (310 million ha) marine reserve network in the world.[6] This chapter considers the achievements of and the future challenges to the National Reserve System and the wider protected area network.

THE NATIONAL RESERVE SYSTEM

The aim of the National Reserve System was first defined in 1993: 'to secure long-term protection for samples of all our diverse ecosystems and the plants and animals they support'.[3] This includes the National Representative System of Marine Protected Areas, which specifically aims 'to establish and manage a system of marine protected areas to contribute to the long-term ecological viability of marine and estuarine systems, to maintain ecological processes and systems'.[6] The National Reserve System is built around the bioregional framework outlined in Chapter 3. In addition to the 85 terrestrial bioregions are 60 Interim Marine and Coastal Regions on the Australian continental shelf, defined by physical surrogates such as seabed type, exposure to erosion, water depth, temperature and geomorphology.


Uluru-Kata Tjuta National Park, NT.
Photo: John Coppi, CSIRO.


Daintree National Park, QLD.
Photo: Bruce Webber, CSIRO.


Alpine National Park, VIC.
Photo: Bruce Webber, CSIRO.


Great Barrier Reef Marine Park, QLD.
Photo: Great Barrier Reef Marine Park Authority.


Prince Regent Nature Reserve, WA.
Photo: Bruce Webber, CSIRO.


Great Otway National Park, VIC.
Photo: Bruce Webber, CSIRO.


Twelve Apostles Marine National Park, VIC.
Photo: Rob Blackburn, Parks Victoria.

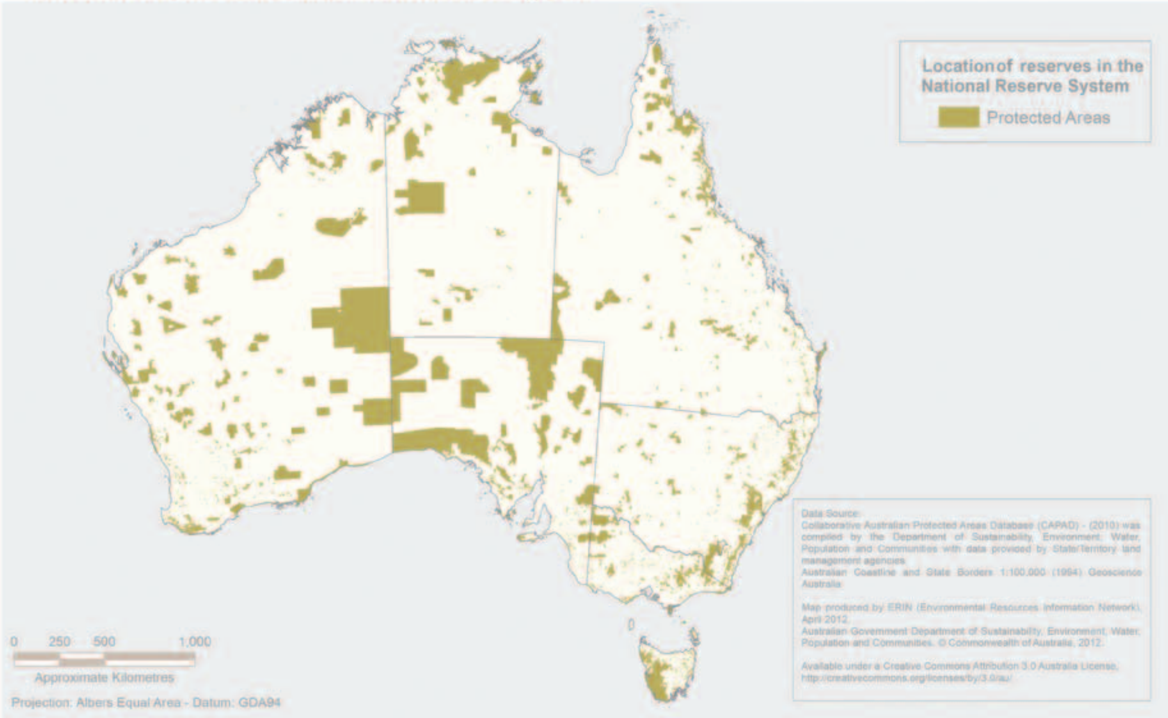

Great Victoria Desert Nature Reserve, SA.
Photo: Greg Rinder, CSIRO.


Nightcap National Park, NSW.
Photo: Bruce Webber, CSIRO.

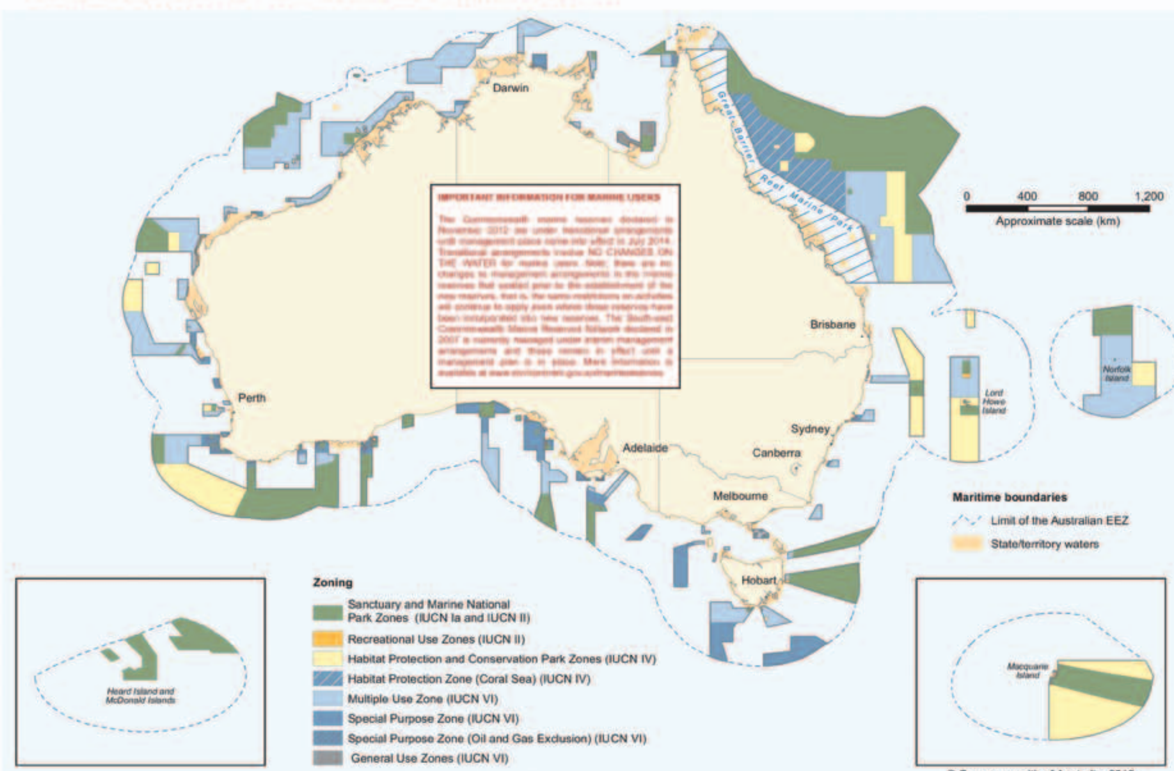

Kakadu National Park, NT.
Photo: Sebastien Burel.

Australia's National Reserve System includes over 550 national parks and state conservation areas, and comprises a spectacular array of landscapes and ecosystems.

Locations of reserves in the National Reserve System



Australia's network of Commonwealth marine reserves



▲ ***Figure 5.1**: The National Reserve System consists of nearly 10 000 protected areas, covering 117 million ha, or over 15% of the continent.[5] In the marine environment, the reserve system now covers 310 million ha or 36% of Commonwealth waters in 70 reserves; it is the largest network of marine reserves in the world.[6]*

Assessment and expansion of the National Reserve System is based upon three criteria known as 'CAR':[7]

- ***C**omprehensiveness* – the reserve system includes the full range of ecological (vegetation) communities
- ***A**dequacy* – reservation size is large enough to maintain species diversity, as well as ecological interactions and evolutionary processes
- ***R**epresentativeness* – reservation of each ecological community encompasses the diversity occurring within that community, including genetic diversity.

Any terrestrial or marine area can be part of the National Reserve System as long as it is designated a 'protected area'. Protected areas require legally binding mechanisms to ensure perpetual conservation; they must contribute to the CAR criteria and be managed to protect and maintain biological diversity either primarily or in combination with other uses, according to one of six categories developed by the International Union for the Conservation of Nature (categories I–IV are strictly protected and categories V–VI allow multi-use).[8] Multi-use protected areas make up more than a quarter of the National Reserve System. The majority of these parks and conservation areas are under state jurisdiction where access restrictions for multi-use can be relaxed (e.g. for logging, cattle grazing, and fishing).

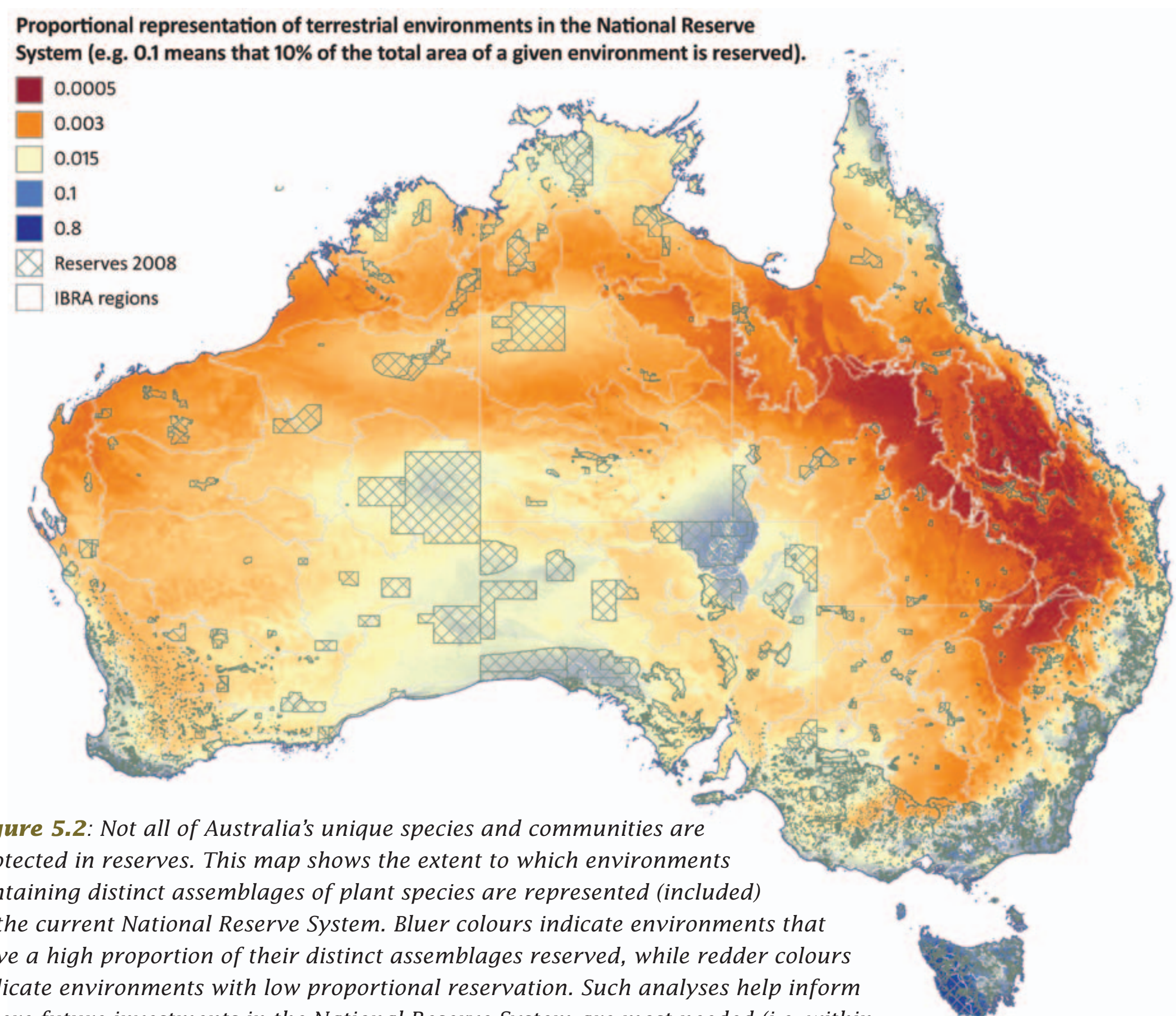
The National Reserve System includes private conservation reserves of 2 million ha. There are also 36 million ha in 53 Indigenous Protected Areas, with more under application, representing more than 30% of the land-based National Reserve System.[9] Similarly, non-government organisations, particularly the Australian Wildlife Conservancy, Bush Heritage Australia, the Nature Conservancy, the Trust for Nature and Birds Australia, also contribute by buying and managing land for conservation. The first three together have spent over $20 million and added 2 million ha to the National Reserve System over the past 20 years or so.

The view from Western Lookout, Cravens Peak Reserve, Queensland. The reserve is owned and managed for conservation by Bush Heritage Australia. Photo: Nella Lithgow, Bush Heritage Australia.

The performance of the National Reserve System has been reviewed against the targets for inclusion by 2030, by both the Department of the Environment and WWF-Australia. These targets are at least 80% of the regional ecosystems in each bioregion, 15% of the area of all extant ecosystems, and critical areas to ensure the viability, resilience and integrity of ecosystem function in response to a changing climate.[10] Combining these reviews, progress to date can be summarised as follows;

- The National Reserve System was nearly halfway towards 15% representation of habitat and species, and all but 2% of the gap could be met from existing, largely intact or remnant ecosystems.
- For comprehensiveness, five to 11 of 85 bioregions met the target.
- For adequacy, 49 bioregions had 10% area protected, and those that didn't still cover large connected areas of eastern and north-western Australia (Figure 5.3).[11,12]
- For representativeness, between 20 and 53 of the 403 sub-bioregions met the target.

The analysis by WWF-Australia concluded that progress has been made but that work remains to be done.[13] A recent assessment of marine elements of the National Reserve System found it not yet fully representative.[14]

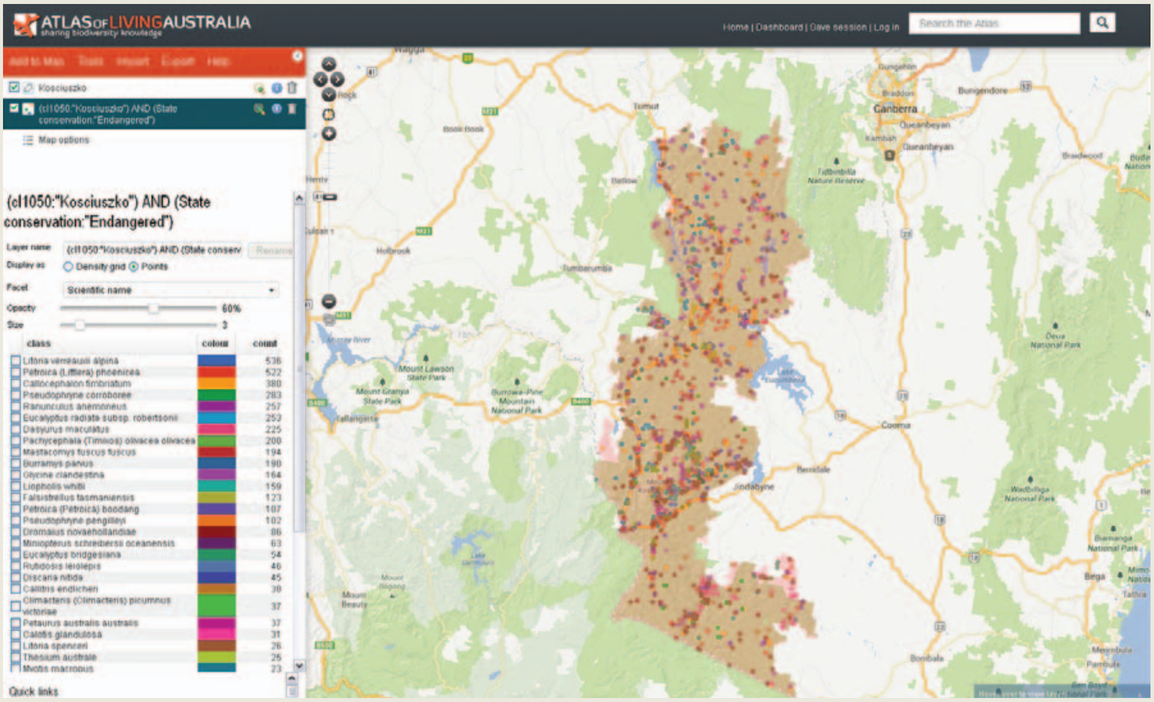


▲ ***Figure 5.2***: *Not all of Australia's unique species and communities are protected in reserves. This map shows the extent to which environments containing distinct assemblages of plant species are represented (included) in the current National Reserve System. Bluer colours indicate environments that have a high proportion of their distinct assemblages reserved, while redder colours indicate environments with low proportional reservation. Such analyses help inform where future investments in the National Reserve System are most needed (i.e. within the redder areas) to ensure that the maximum number of unique species are protected.*[15]

Modelling and mapping of fine-scale patterns of biodiversity are enabling assessment of the representativeness of the National Reserve System with new rigour. The *Atlas of Living Australia* is assisting this process (Box 5.1).

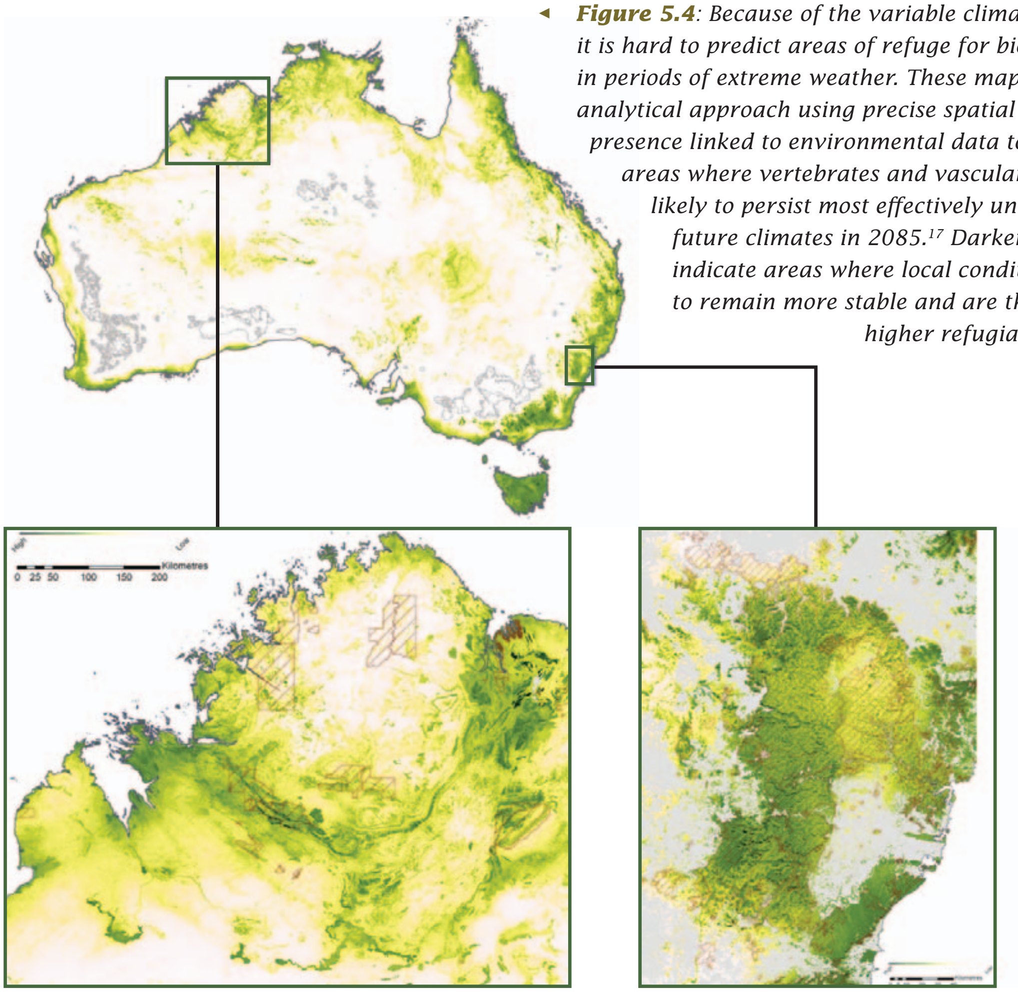
Box 5.1: Designing better reserves using online data tools

Historically, it has not been easy to see how well the chosen elements of the National Reserve System match distributions of threatened and endangered species or their preferred habitats. The *Atlas of Living Australia*'s mapping and analysis tools now allow these sorts of analyses to be undertaken easily. The *Atlas* instantly accesses all available data repositories, including its own up-to-the-minute data for species observations, in order to create distribution maps for any Australian species. Using the mapping tool it can highlight conservation reserves, such as a national park (Figure 5.3). The *Atlas* can then produce a report on all threatened and endangered species in any area defined by the user, and show to what degree that reserve offers protection to endangered and threatened species known to occur in that region.



▲ ***Figure 5.3****: Screenshot showing endangered species in Kosciuszko National Park, with occurrence records filtered to show different coloured points for each species.*[16]

The National Reserve System also needs to take account of responses of biodiversity to times of stress. In extreme conditions, many plants and animals retract to refuges. As pressures increase, especially with climate change, such refuges will become the last stand for endangered species, so identifying and protecting them is critical for protected area networks. They may be easy to spot in areas of high local ecosystem diversity, for example in topographically varied escarpments where whole communities can do well. But in many cases refuges will be subtle or isolated, important for one or only a few species. Combining distribution modelling, satellite imagery and Indigenous knowledge will help predict their presence and assist management through incorporation into formal reserves or through off-reserve management (Figure 5.4).



◂ ***Figure 5.4***: *Because of the variable climate of Australia it is hard to predict areas of refuge for biodiversity in periods of extreme weather. These maps show an analytical approach using precise spatial data on species presence linked to environmental data to predict areas where vertebrates and vascular plants are likely to persist most effectively under projected future climates in 2085.*[17] *Darker greens indicate areas where local conditions are likely to remain more stable and are therefore of higher refugial potential.*

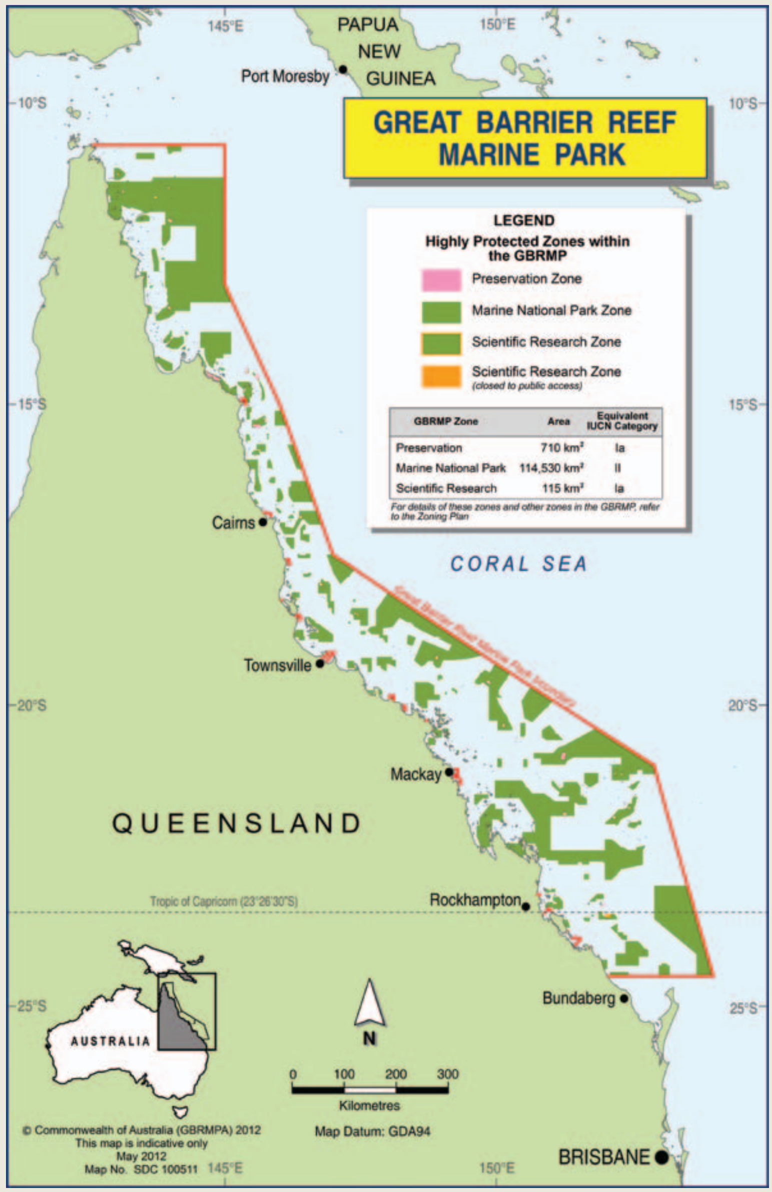
SYSTEMATIC CONSERVATION PLANNING

Systematic conservation planning aims to inform decision-making by identifying which areas of land and sea will preserve the most biodiversity for the least cost.[18] All available spatial data on species occurrence are overlayed with environmental information onto the areas already protected. This can identify new locations most likely to contain habitats not represented in any existing protected area. Using millions of records of more than 20 000 species of plants, vertebrates and invertebrates, together with remotely sensed environmental data, this analysis is being applied to predict how the representativeness and adequacy of the reserves might also be affected by future shifts in biodiversity composition under future climates (Figure 5.2).[19] Landscapes can then be 'designed' that should maximise the capacity of species to persist and adapt (Figure 5.4) through linking reserves, off-reserve conservation, environmental stewardship, and habitat restoration. With all available biodiversity data fully analysed, community-based decision-making approaches on reserve design noted in Chapter 4 and illustrated in Box 5.2 can be applied.

Systematic conservation planning is also used to identify optimal areas of private land for conservation covenants or carbon forestry, for example. In most cases alternative areas could be proposed, providing planners with needed flexibility when negotiating the design of reserves that will affect multiple interest groups. A principle of 'complementarity' can be applied, whereby areas are selected based on data analyses to protect the greatest possible range of unique and important biodiversity features for the least financial cost – say, five populations of each species and 10% of each ecosystem – rather than just selecting sites with the most species or ecosystems.[20]

Box 5.2: The Great Barrier Reef Marine Park: systematic conservation planning

In 2001 the Great Barrier Reef Marine Park Authority initiated a rezoning to protect biodiversity through 'No-Take Green Zones'. Planners were faced with a complex problem of selecting sites in view of many (often conflicting) views and objectives. Social and scientific committees were appointed to represent stakeholders, to analyse the socio-economic setting, and to establish political support for implementation. The conservation objectives were to represent at least 20% of each of 70 bioregions. The socio-economic objectives were to distribute negative effects equitably, such that 'everybody is only a little bit unhappy' (e.g. by maximising overlap between No-Take Zones and no-go areas of cultural significance), and to create reserve networks that are practical for users and managers. Draft plans were revised through expert input, public consultation and reanalysis. The decision model showed the consequences of different plans, and the committees negotiated to arrive at the final plan – a Marine Park that covers 33% of the region, making the largest single marine park in the world (Figure 5.5).[21]



▲ ***Figure 5.5****: The Great Barrier Reef Marine Park showing areas where fishing is prohibited (dark gray shading). Map courtesy of the Spatial Data Centre, Great Barrier Reef Marine Park Authority, © Commonwealth of Australia, 2013.*

OFF-RESERVE CONSERVATION THROUGH WHOLE-OF-LANDSCAPE MANAGEMENT

Off-reserve management is also important for ensuring that the protected areas of the National Reserve System provide for long-term conservation in the landscape. Off-reserve conservation areas on private land complement the National Reserve System, but have less stringent criteria for protection from clearing and management of pests and weeds.

As over 60% of Australia is in private tenure, mechanisms for conservation on private lands (Table 5.1) are vital to the success of the National Reserve System in helping conserve species and ecosystems. Land-stewardship programs create markets to pay land-owners to enter agreements for protecting remnant ecosystems and managing threatening processes such as fire, grazing, weeds and feral animals. Grant schemes aim to develop environmental markets that encompass biodiversity benefits – for example, carbon storage and environmental flows of water – through management and restoration of land.[22] Off-reserve marine conservation areas are massive by comparison to those in the terrestrial National Reserve System. Closures to commercial fishing designated by state and Commonwealth fisheries management authorities have been larger than formal Marine Reserves on the continental shelf. Many such areas are designated as multi-use however and can be reopened for fishing or used at some future point to extract natural resources.

Table 5.1: Mechanisms and instruments for conservation on private lands

Type	Objective	Land manager	Duration
Protected areas included in the National Reserve System			
Privately owned reserves	Land and sea biodiversity conservation and may be multi-use	NGOs and other private owners	In perpetuity
Indigenous protected areas	Land and sea biodiversity conservation and may be multi-use	Indigenous owners	In perpetuity
Land conservation covenants	Nature refuges and restricting land use	Non-government organisations, freeholders	In perpetuity
Off-reserve conservation areas			
Grant schemes and auctions	Biodiversity restoration	All	Ongoing
Voluntary agreements for land management partnerships	Duty of care to biodiversity	All	Ongoing
Informal voluntary protection of habitat	Undocumented	All	Ongoing
Environmental stewardship incentives	Biodiversity management of land and duty of care	Farmers	Ongoing
Industry standards	Wildlife management on land and sea	Industry	Ongoing
Offsets or 'BioBanking' (see Chapter 11)	Land and sea biodiversity conservation	Industry and local government (e.g. mining and urban development) – off or on multi-use protected areas	Duration of impact

Many reserve design approaches worldwide are adopting 'connectivity conservation'.[23] Connectivity conservation emphasises connections between habitats across the landscape, aiming to allow movement of plants and animals through a region regardless of whether or not land is part of a formal reserve system (see also Chapter 7). The approaches include habitat corridors, enhancing the size and condition of remnant bush, and coordinated management of larger tracts of private and public lands. Connectivity is also fundamental to marine reserves, where establishing networks of protected areas as 'stepping stones' to aid species to persist and adapt to change is widely accepted. Implementation of such approaches is the focus of several government initiatives.

Connectivity allows species such as this sugar glider, Petaurus breviceps*, to move across the landscape, helping them adapt to change. Photo: Eric Vanderduys, CSIRO.*

While the ideas of connectivity may seem to be common sense, key questions remain around its benefits:[23]

- What types of habitat linkage will favour movement of desirable species?
- What are the relative benefits of connected corridors, as opposed to increasing the area of habitat in a landscape regardless of connections?
- Will connectivity encourage the migration of native species while at the same time ensuring containment of invasive non-natives?
- When will connectivity generate relatively low conservation benefits compared to other potential actions?

In many areas, particularly in the face of climate change, it will be just as important to maximise the size and coverage of individual reserves as to build connectivity.

CONCLUSION

Sustaining Australia's biodiversity across a network of protected areas, complemented by whole-of-landscape conservation management, is among our greatest environmental challenges. An excellent start has been made on the National Reserve System, and on the necessary management to create networks between reserves across the landscape.

FURTHER READING

Dunlop M, Hilbert DW, Stafford Smith M, Davies R, James CD *et al*. (2012) *Implications for Policymakers: Climate Change, Biodiversity Conservation and the National Reserve System*. CSIRO Climate Adaptation Flagship, Canberra. <http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/adapt-national-reserve-system.aspx>.

Williams KJ, Ferrier S, Rosauer D, Yeates D, Manion G *et al*. (2010) *Harnessing Continent-wide Biodiversity Datasets for Prioritising National Conservation Investment*. CSIRO Ecosystem Sciences, Canberra.

Indigenous perspectives on biodiversity

Fiona Walsh, Peter Christophersen and Sandra McGregor

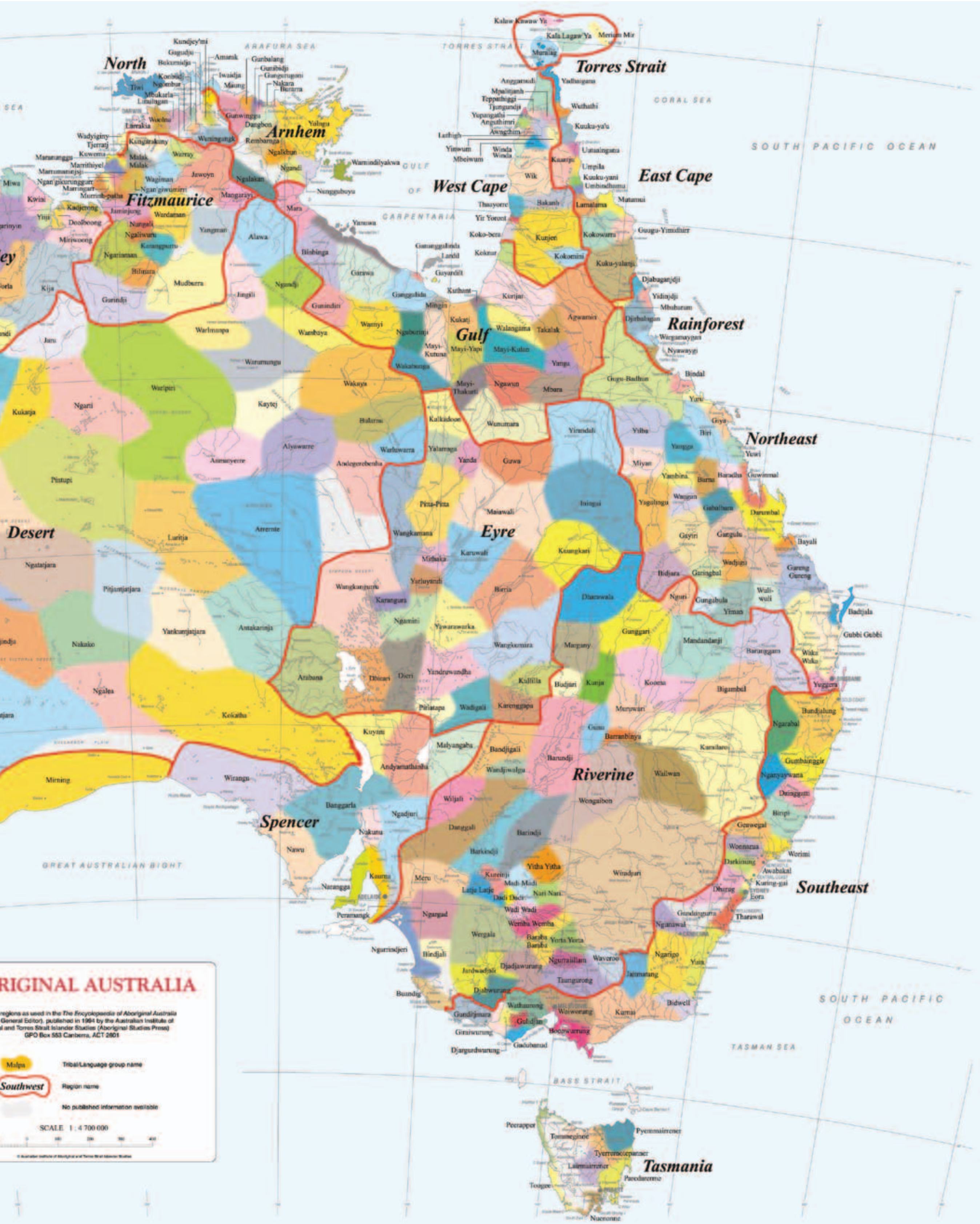
Key messages

- Aboriginal concepts that connect people to their 'Country' and to living things through a web of relationships are akin to the meaning of the English term 'biodiversity'.
- Aboriginal people were, and in numerous cases still are, reliant upon plants, animals and ecological processes because bush foods, medicines and materials are components of Aboriginal economies, personal identity and culture.
- Long-term observations, sustained residence and oral history inform Aboriginal people about changes in biodiversity.
- Aboriginal solutions to declines in biodiversity focus on people and on their practical on-ground actions, particularly burning and the manipulation of target species for hunting and gathering.

INTRODUCTION

Aboriginal people shaped the pre-colonial environments of Australia for 50 000 years.[1] Today, formalised Indigenous land and sea management programs are increasingly significant in Australia, the origins lying in the relationships between Aboriginals and Torres Strait Islanders and their customary estates on land and sea – or 'Country' (Figure 6.1).[2,3] It would be foolish to ignore Indigenous knowledge in helping shape future biodiversity management and research. So it is that this chapter gives voice to Peter Christophersen and Sandra McGregor, Aboriginal managers of lands adjacent to Kakadu National Park, Northern Territory.[4] Co-author and scientist Fiona Walsh recorded discussions with Peter and Sandra and edited the text; their words are presented in italics, usually as one voice. Like most Aboriginal people, Peter and Sandra believe it inappropriate to speak for someone else's Country. Hence, following their words on each topic, Fiona provides a wider perspective; then, in the chapter's final section, she discusses recent national trends in Indigenous natural resource management.

▸ ***Figure 6.1****: There were more than 250 Aboriginal languages across Australia. This map indicates linguistic diversity. It is through language that people conceptualise and describe the variety of things on their lands. Today, language is one basis for Aboriginal protected areas, governance and decision-making related to biodiversity.*[5]



ARAFURA SEA
TORRES STRAIT
CORAL SEA
SOUTH PACIFIC OCEAN
GULF OF CARPENTARIA
GREAT AUSTRALIAN BIGHT
TASMAN SEA
BASS STRAIT
North
Torres Strait
Arnhem
Fitzmaurice
West Cape
East Cape
Gulf
Rainforest
Northeast
Desert
Eyre
Riverine
Spencer
Southeast
Tasmania
RIGINAL AUSTRALIA
Malpa
Tribal/Language group name
Southwest
Region name
No published information available
SCALE 1 : 4 700 000

AN INDIGENOUS PERSPECTIVE ON BIODIVERSITY

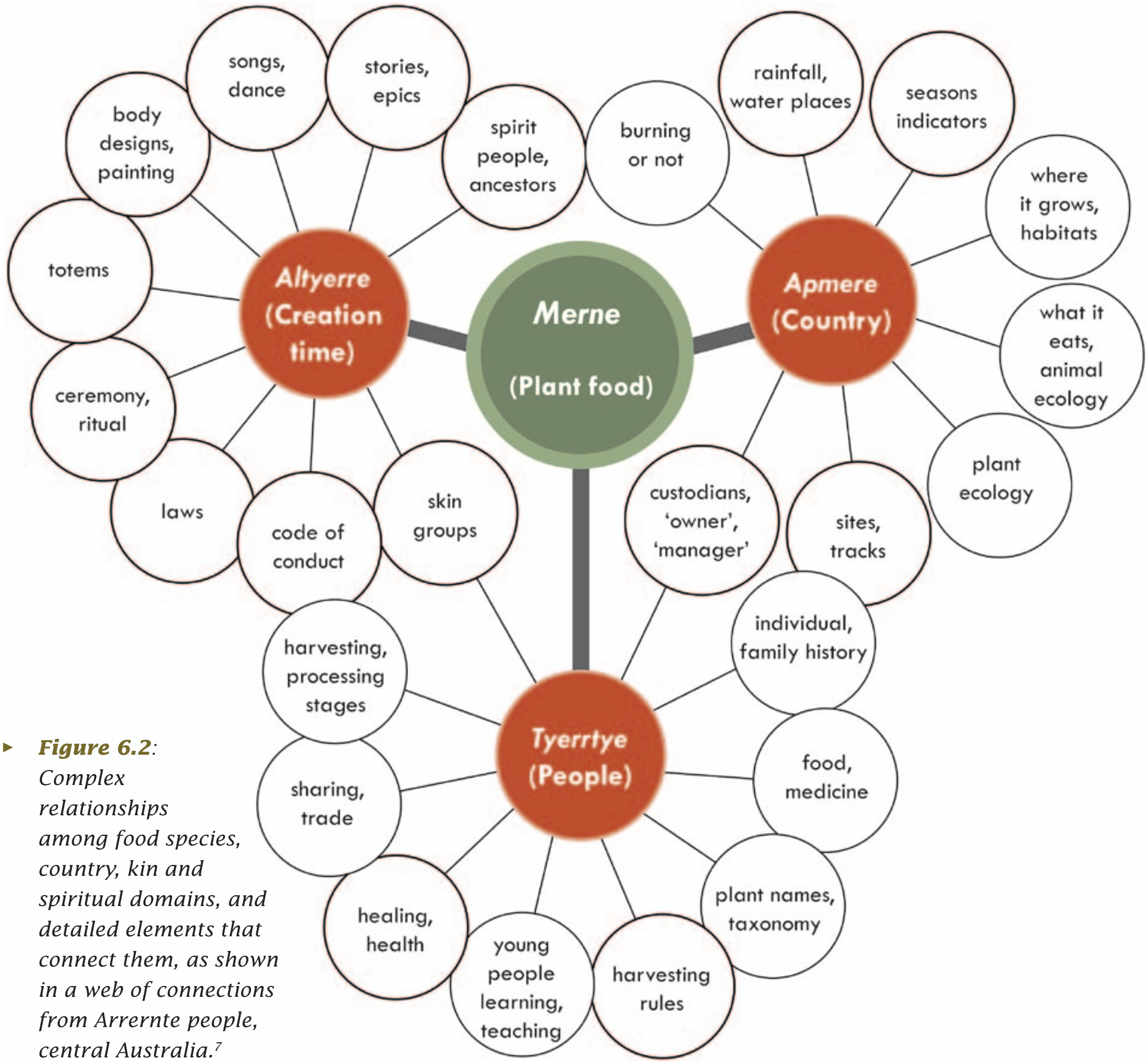
What is biodiversity and why is it important?

We look at Country as everything all living together. When you look, it's healthy because everything's got order and connection. Everything living and non-living: the birds and the rocks, and the relationship things have with each other. It is not just animals and plants. It includes humans, weather and all – not just those things that are living there but also the relationships, how everything functions together. In our eyes, humans are a part of the system. Biodiversity is not a word we use.

For us a healthy wetland means looking at the health of all. We're looking at all the individual species of plants that would enhance magpie geese and ducks. We know how to manage those plants to enhance the geese. Geese are important because we eat them. They are our bush foods. The other night we were talking about rewards. For everything we do here, there's something that we get out of it. We're not just working and working with no benefit. This reward might be more or bigger geese, or it might be easier to hunt wallabies. A benefit for non-Aboriginal mob is to have this pristine-looking place with plenty of animals. Ours is the same, except that we also need to utilise the animals. We have an understanding of how all those pieces benefit each other. Then at the point when those pieces stop benefiting we've got to jump in and help nature along a bit.

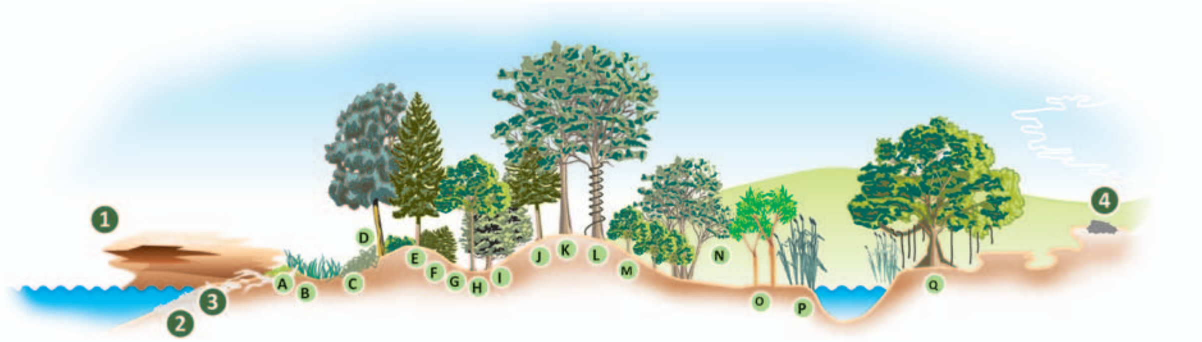
The many Aboriginal dictionaries contain numerous references to plants, animals and ecological processes, but it is doubtful if in any language there was a single term that directly translates to 'biodiversity'. Related words do exist, for example in Yanyuwa[6] *yumbulyumbulmantha ki-awarrawu* – all kinds of things from Country – and in Arrernte, *anpernirrentye* – kin relationships among all things.[7] Both terms embed people among plants and animals and their interrelationships, all of which is a result of the creation of the world in the time known as the Dreaming when the laws governing Country and people were established (Figure 6.2). Aboriginal people commonly refuse to separate people from ecosystems, or the social from the natural and spiritual worlds.

For Indigenous people, native plants and animals provided all food, medicine, materials, and life necessities equivalent to those from supermarkets, pharmacies or hardware stores.[8] Precise classifications often exist; for example, Yanyuwa people from around Borroloola in the Northern Territory recognised 21 categories of bony fish and eels classified by habitat and utility, and 16 terms for *waliki* (dugong, *Dugong dugon*) of different gender and life stages.[6] Aboriginal languages also encoded details of landforms, climate and ecological processes (Figure 6.3). Today, some Aboriginal people are still materially dependent upon native species.[9,10] For any single species used as a resource, several others are often needed to make it useful. To treat a burn, for example,



▸ ***Figure 6.2***: *Complex relationships among food species, country, kin and spiritual domains, and detailed elements that connect them, as shown in a web of connections from Arrernte people, central Australia.*[7]

a healer in desert Australia would apply the silk bag of a processionary caterpillar (*iwepe, Ochrogaster* spp.) with a poultice of emu bush (*utnerrenge, Eremophila longifolia*) (Figure 6.4). Five further species were also required for effective healing, but at a step distant in the process.[11] In turn, each of these species has multiple other interrelated uses, as expressed by Peter and Sandra: *how everything functions together*.



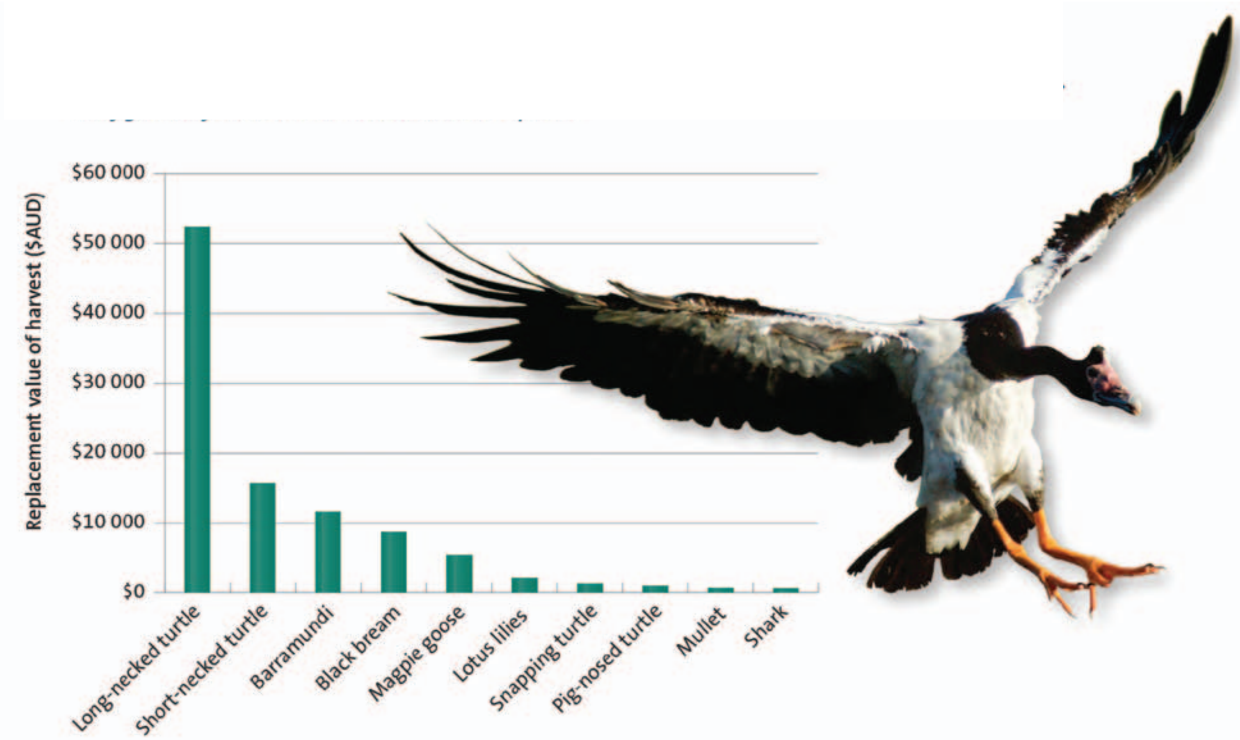
▲ ***Figure 6.3****: One of ten land units recognised on Yanyuwa Country, Northern Territory. These physical landscapes describe the habitats that underpin species and their ecological connections, and the places that are home to Yanyuwa. The Yanyuwa spiritual view of the environment is interlaced with this physical view.*[6]

How is biodiversity tracked?

We know how Country has changed from talking to old people like Sandra's grandmother. She's about 74 years old. Sandra took her to her place, where once there were freshwater billabongs. The old lady said there used to be lilies; you could get turtles, millions of them. Now those billabongs are salt water, a different landscape. The old lady sort of knew the area but didn't know the place she'd landed, it had changed so much in 50 years. There are changes in our lifetime too. Sandra visited Boggy Plain in 1986, and then we both went there in 2000. Sandra looked at it and thought, 'No, this is not how it is supposed to be. It needs fire. It needs a helping hand to get back the numbers of plants and animals that should be here.'

We know how Country is changing by keeping an eye on what is happening. Hunting gets you out there, and you pick changes up by sight or smell. For example, we live a half-hour drive from the billabongs. Last night there was a north wind and we could smell salty mud. We knew what was happening out there. It is high tide. Salt water is going over the mud. The geese are digging the mud again and again. They are turning the mud to get food to condition themselves for one last flight before the Wet. This is going to be our last chance to get fat geese before they lose condition (Figure 6.5).

▸ ***Figure 6.4***: *In an Aboriginal worldview various ecological–human connections need to occur to make a natural product suitable for human use. Arrernte people describe the connections between insect and plant species needed to make a medicinal dressing. The iwepe (*Ochrogaster lunifera*, itchy grub, processionary caterpillar) is critical to these connections. This diagram records some of what Arrernte people say about the biology of connected species. The knowledge documented is the intellectual and cultural property of Arrernte and other desert people familiar with these species. Photos portray Veronica Dobson, Patricia Drover, Rena McCormack. Photos: (3) You Ning Su, Australian National Insect Collection; (9) Josie Douglas, CSIRO; (13) B McDonald; (14) Veronica Dobson, CSIRO; others by Fiona Walsh, CSIRO.*[11]



▲ ***Figure 6.5**: The volume of bush foods, such as magpie geese,* Anseranas semipalmata, *turtles and fish, that were eaten by Aboriginal people at Daly River from 2008 to 2010 was equivalent to $100 000 of store-bought foods. This figure only shows the ten 'most valuable' species.*[10]

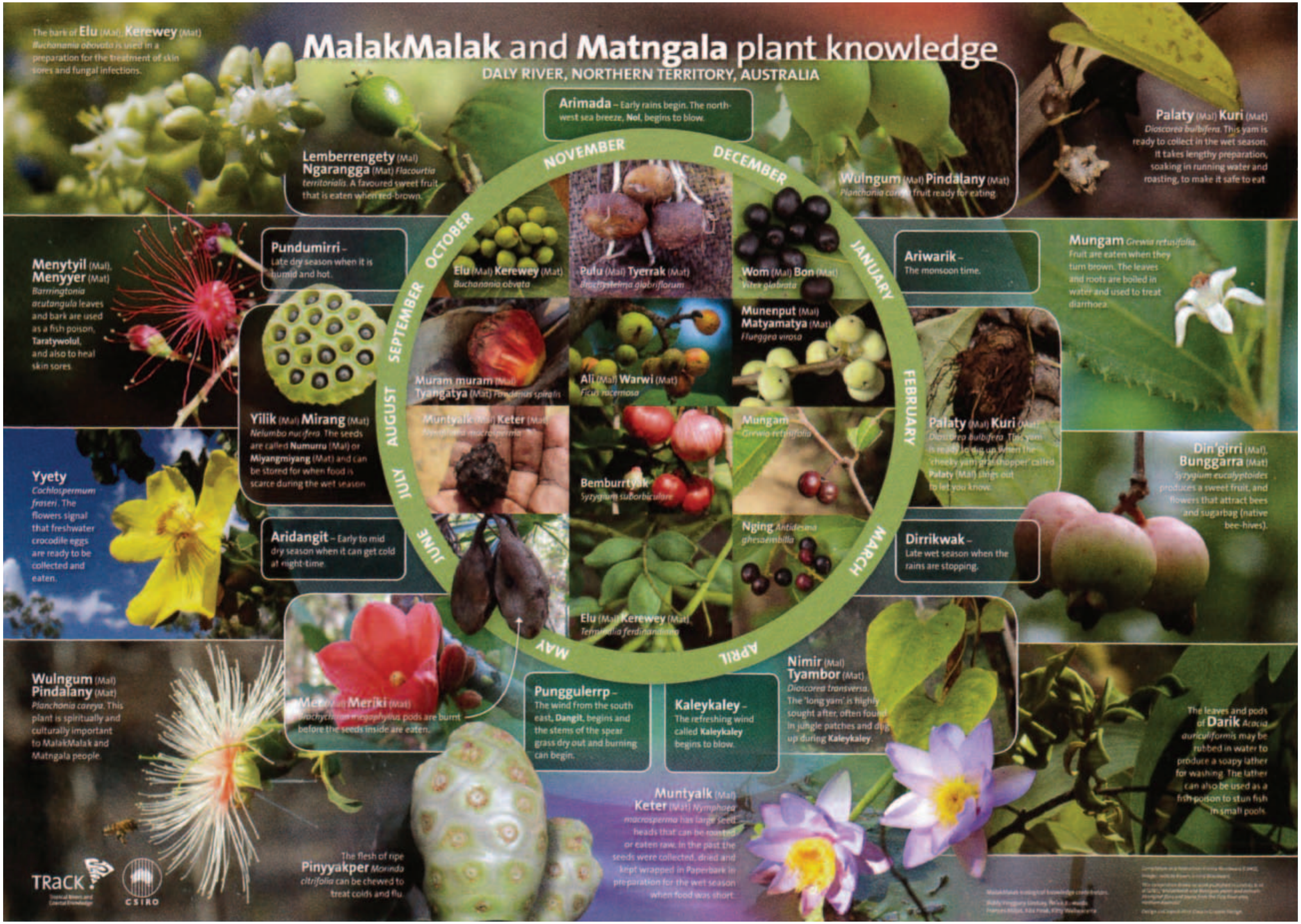
Aboriginal people living on or close to their Country accumulate observations of species and ecological interactions over a lifetime and pass them across generations, allowing tracking and monitoring of change. Such observations are now frequently represented as ecological calendars (Figure 6.6).[12] In contrast, scientists are usually short-term visitors who require historical documents to identify changes.

What is the condition of biodiversity?

It is hard to say really whether things are bad or good. We know it is getting worse. There is a big decline in mammals. That's really bad. They are missing and we're not really sure what's doing it, whether it's been cane toads coming in or bad burning or other things; we just can't put a finger on it. We look at one area of woodland and it seems in bad condition, then another area looks in good condition yet still doesn't have mammals. That's confusing. But it does not directly affect us as we don't hunt and eat those little mammals.

But then you see little things tweaked that benefit an animal. The cane toad came in and the goannas and a lot of snakes are disappearing. Now many ground-dwelling birds don't have those predators hammering them so there are more birds. Perhaps there is a new balance. The goannas used to dig up the long-necked turtle eggs, but now we're getting more little turtles. Maybe. We're just wondering about these links.

The goanna[13] *is very important to us. When the cane toad jumped in we found dead goannas everywhere. That tore our heart out. But we didn't rush out and hunt goannas down before they all got killed. We decided to let this change run its course. We decided we can't hunt that goanna*



▲ ***Figure 6.6***: *Plant knowledge of flower and fruiting times represented in a seasonal calendar from the Daly River, Northern Territory.*[12]

anymore. We've got to look at how this animal adapts to the toad. We've found some goannas are still mating, and killing cane toads. We've found baby goannas, so there's a hope that there might be populations in future. The only goanna killed in a while was by an old lady. She had to get one because her grandson was nine years old and she needed to show him you eat goanna. 'This is how you kill it. This is how you prepare it.' Every now and then we have to sacrifice a goanna. The next generations need to know this is the way you hunt it, how you manage for that animal.

About hunting, different people have different ways. Some clans spend time to look after their land. They manage it so that their families can get food, more animals. But sometimes it is a sad situation. Some families can't manage their area. They might come and take from someone who is managing their land better. They take animals, get as much as they can, take and take. This has only happened a few times but it's hard.

The porcupine [echidna, Tachyglossus aculeatus*] should be walked and tracked for, hunted for food. We don't see this animal very often, and have to work hard for it. Now if we find a porcupine on the road we walk them into the scrub. We rub the tracks out so no one can see to hunt them. We let them go because we worry maybe we're not managing the place properly or maybe something else is harming these animals. But our biggest problem is that if we don't utilise that animal then we might not remember how to manage for it.*

This idea we have of biodiversity, of how everything's linked – that's why we feel that it's important to kill an animal every now and then. Doing this reminds us where this animal fits and how we've got to manage for it. Every time you lose an animal you lose a bit of knowledge – then animals and knowledge are gone.

Long-term recollections by Aboriginal people indicate that the diversity of bush foods and resources is often declining and associated cultural knowledge fragmenting.[14] Declines of species are strongly felt because they affect nutrition, health and psychological wellbeing – people speak of being wounded or struck ill by these losses. The costs of biodiversity loss are obviously higher for those more reliant upon local species for food. Further, older Aboriginal people express concern at losing opportunities for future generations to learn, for they see such knowledge as critical to the cultural identity of their children.

The environmental weed buffel grass, Cenchrus ciliaris, *has invaded riparian systems of central Australia and displaced many bush food species. Here, Veronica Dobson points out an isolated plant of native pear,* Cynanchum floribundum. *Although it persists, it is vulnerable to both weed competition and wildfires fuelled by the weed. Native pears are highly valued for their edible fruit and foliage, and as hosts to important insects. Photo: Fiona Walsh, CSIRO.*

Aboriginal people identify many threats to the abundance of resources, some concurring with those seen by scientists. Sandra and other Aboriginal people say that bush food plants and animals are being pushed out by weeds (or 'stranger plants') and feral animals.[15] Some introduced animals have replaced native animals as foods.[16] Additionally, Aboriginal people attribute declines to human factors; for example, the passing away of rainmakers was said in some regions to explain a decline in rainfall.

What solutions are there to biodiversity decline?

Solutions? We're flat out trying to make a living and can't spend as much time managing this land as we want to. We spend a lot of time out here. With more time we'd be looking after cultural places, shooting feral animals, spraying weeds, burning, there's just never enough time. People's lives have changed and everyone is flat out doing other things. We're living here but still we're breezing over Country. We go out, assess things, utilise areas, do maintenance or management. It's hectic but even so we can't put in the time and effort needed to look after Country in fine detail.

The majority of Australians live in cities. They visit our Country, they say it's beautiful. They expect that a national park will be looked after well, but really you can't do it properly. There's a lot of Country where countrymen are living, trying to make a living, but they can't look after it really well because there's not enough money for it. Everyone's got to get little jobs. More money for countrymen to get rewarded for looking after Country properly would really enhance that biodiversity aspect.

There's value in keeping the land and improving its health. We know we could keep Country healthy if there was an economy built around that. Something like carbon farming, then there'd be a lot more Aboriginal mob out here working and looking after the place. Our primary role could be to manage the landscape and make sure it's all as good as we can make it. Surely that's got to be of benefit to all Australians.

On the wetlands we look at everything. At a point we say 'Oh! This species of plant is not doing so well, and so there aren't enough geese here.' Or 'It's getting harder to get turtles. So in the next

Aboriginal fire management has increased the biodiversity and resources on Yellow Water's wetlands. Areas densely covered in mudja, Hymenachne acutigluma, ***(a)*** *are replaced after burning by a variety of habitats, larger areas of open water and more species, such as wild rice and spike rushes* ***(b)****. The number of animals favoured by Aboriginal people to eat, such as long-necked turtles and magpie geese, increases significantly. Photos: CSIRO.*

couple of years, we've got to burn this wetland.' We jump in to reset the clock. We know that when those plants come back after a burn the birds will be attracted back. We change the vegetation so that the goose benefits, the plants benefit, and we benefit.

For woodland, it's similar. We manipulate the grass with fire – it creates green pick to encourage animals to feed. We put a certain fire in and it'll help different grasses to grow and then it brings in the animals that we want – might be an agile wallaby, black wallaroo or other kangaroos. You've got acute knowledge of an animal built up over such a long time of managing for it. If someone says 'Oh! We're going to burn this off' and not think about the animals, that's craziness. Before we burn we're always thinking about what's happening in that area with its plants or animals.

Science can provide another layer of knowledge, particularly on long-term predictions. But sometimes we have different views. Scientists might look at climate change like it's going to damage the wetlands. We're saying though 'In the meantime weeds are going to come in and destroy a lot of those wetlands before climate change hits us. Then we'll need salt water to come in to knock out the weeds.' But that other layer of technical knowledge can help us predict. It is important in helping us make long-term decisions about Country. Science gives deeper understanding of future issues. Then we've got to work out how we work to adapt to all that change.

Many Aboriginal and Torres Strait Islander people combine traditionally derived and Western solutions in the face of biodiversity decline. Sandra and Peter emphasise the rewards for managing Country that include hunting. They also operate a small-scale business to harvest native seeds for mine-site rehabilitation. Enterprises based on natural resources for rehabilitation of vegetation, production of artefacts and niche foods or bush medicines are important to many Aboriginal groups.[17] These enterprises rely upon a diversity of species.

Karnu (Nancy Taylor) hunting on a recent burn with high species diversity bordering a long-unburnt area dominated by spinifex in the Great Sandy Desert. Photo: Fiona Walsh, CSIRO.

Peter Christophersen, Sandra McGregor and their children. Children are guided in the ignition of small, careful, safe burns and so gain experience from a young age. Photo: Randy Larcombe.

The future

What I'd like to see in the future? I'm scared of that question because it's not going to pan out how I might want it to be. I'd like to see this country how it was before it was proclaimed as a park, where Aboriginal people are more active on their lands and live on their clan areas on outstations rather than in communities. Where we teach, pass knowledge on and preserve it. That's the only way I see biodiversity keeping in good order.

But we run our own business; we contract to the mining company, and that takes a lot of our time. Our children, we've got two that have left school and gone into a mining company. At the end of the day, you have to earn money. You can have all the knowledge but it's not going to help you get an income to buy a car or visit another country. We hope that all our kids will continue our work, but realistically it might be one or two of our four children. One older girl has a lot of knowledge and a good attitude. The other one, he enjoys Country but really he loves computers. It's not worth us saying 'No! You shouldn't do this, you should do that.' It'd be better to let him get that technology under his belt, bring him back and get him to apply it to managing the Country. If we don't take on new ideas then we won't be able to operate into the future. It's the mixture of the old and the new. He might be good at understanding all those concepts, whereas the girl would be good at doing the physical jobs. They complement each other – that's great.

Connection and care inspire us. The more we do, the more we understand, the more knowledge we gain. It's interesting finding out more about how things work, how the plants, animals and weather inter-link. Learning is really inspiring. So is teaching kids, teaching other people – sharing our little bit of knowledge and hopefully winning over another person to keep looking after this Country.

All people want a future for their children, and many Aboriginal people see the health of Country as integral to this aim. Feeling good about the future leads to action to make things better. Biocultural diversity will not be maintained through inaction or negativity, which weaken people and perpetuate apathy. When the careful, pragmatic optimism expressed by Sandra and Peter is aggregated in concept through many Aboriginal people and groups across Australia, it provides a pointer towards significant national benefit.

INDIGENOUS LAND AND SEA MANAGEMENT: NATIONAL APPROACHES

Overview

The 2011 State of Environment report identified increasing formal involvement of Indigenous people as one of four standout trends in environmental management in Australia over the last decade (Figure 6.7). Major components are summarised in Table 6.1.[2]

Table 6.1: Drivers of contemporary Indigenous land and sea management

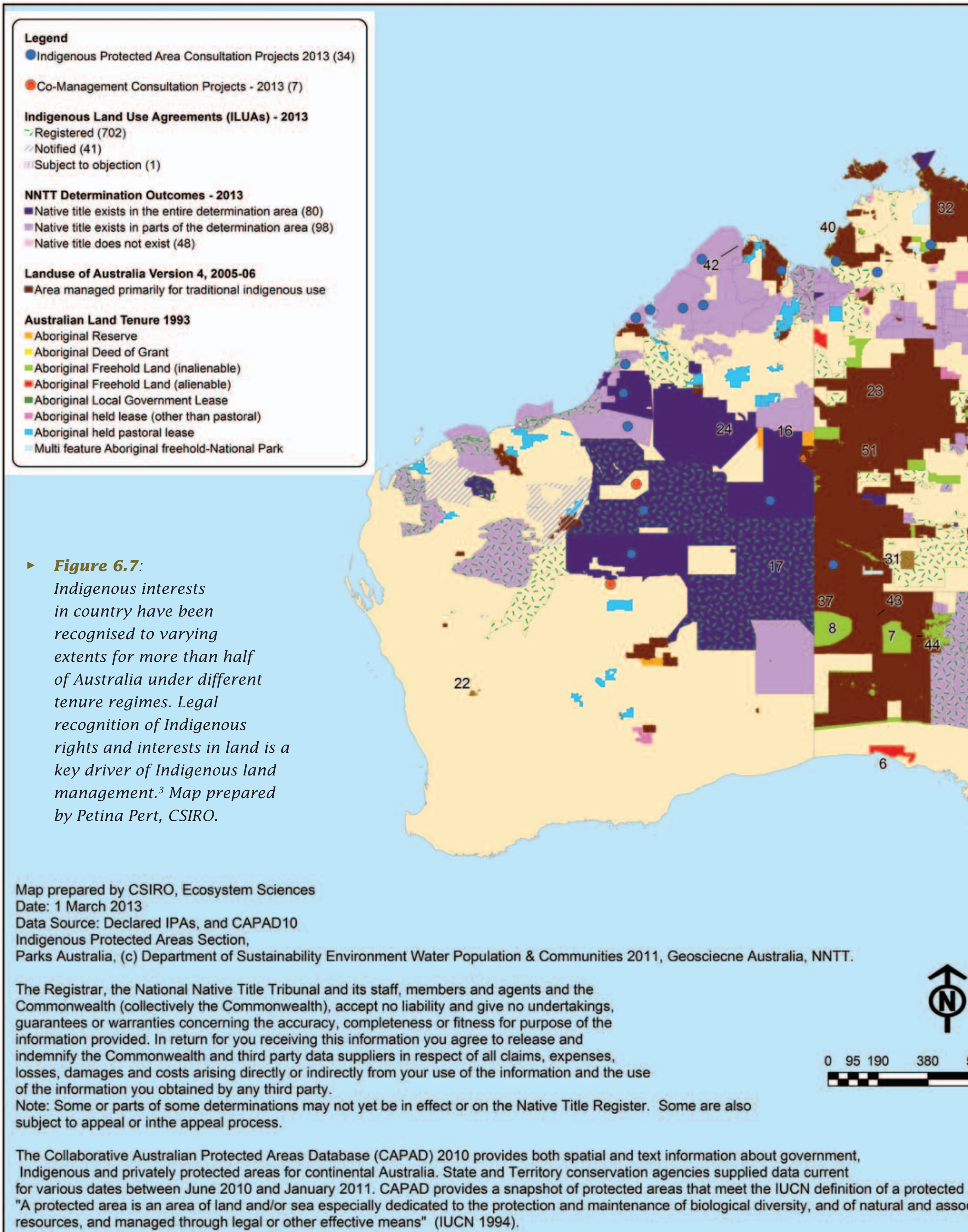
Major drivers	Outcomes
Customary obligations to younger generations and Country	Culture as primary basis for Indigenous management of Country; education of Aboriginal children in cultural practices; strengthened relationships among people, their Country, species and Dreaming
Recognition of Indigenous rights in land	Indigenous interests in land now recognised over 60% of Australia: through tenure; where Native Title is held over land in whole or in part; or through Indigenous Land Use Agreements with other users
Indigenous leadership at multiple levels of decision-making	Opportunity for people to lead initiatives, such as advisory committees to government ministers, regional alliances and community ranger groups
Markets for land management and associated goods and services	Openings for Indigenous owners to benefit from programs enhancing natural resource management, such as commercial harvest of bush resources and the Indigenous Carbon Farming Initiative
Indigenous and co-managed conservation areas	53 declared Indigenous Protected Areas covering 36 million ha, 30% of the National Reserve System, and increasing numbers of co-managed national parks
Multiple benefits	Environmental benefits – reductions in weeds and feral animals, healthier fire regimes, fisheries management, border protection, carbon sequestration – married to wider social and economic gains in health and wellbeing via reduced antisocial behaviour, reduced welfare payments, and increased revenues from the closely related arts and crafts industries
Investment	Growing confidence in Indigenous environmental management leading to increased proportions of applicable Commonwealth Government funding (less than $1 million a year in 1992, about $90 million in 2012)

The rising success of Indigenous land and sea management stems principally from motivation, because activities on Country are driven by an expression of identity. Traditionally oriented Aboriginal and Torres Strait Islander people believe that their totemic Dreaming characters shaped both ecosystems and human existence.[6,7] Plants, animals and landscapes are foundations of identity at several levels, through creation by ancestral characters of a person's sense of self, family and place. And human identity is matched by responsibility for undertaking activities on Country that are needed to keep it 'alive', actions that are critical to ecosystem function. Increasingly, ecologists and natural resource managers see people as a part of ecosystems too, but they tend to classify people as 'resource users' or 'managers' and conceive these roles to be held by different individuals or groups. Aboriginal people connected to Country believe they are inside an ecological system – they hold and are held by Country, and their roles are both users and managers.

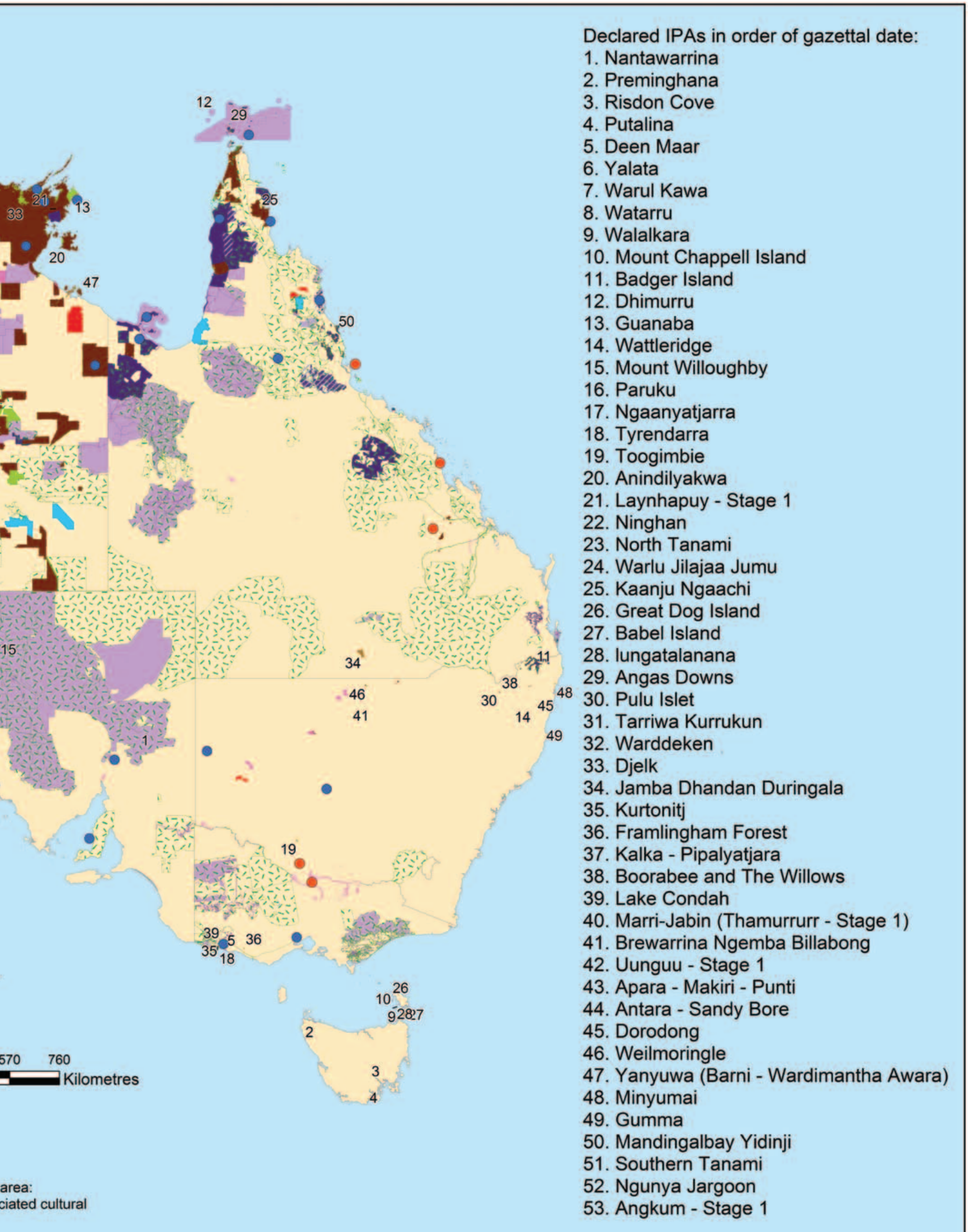
Indigenous people believe that their activities continue to exert practical and spiritual influence today. Both deliberately and inadvertently, people manipulate resources on land and near shore through hunting, burning, redirecting surface water, dispersing plants, cleaning water sources, and many other practices.[1,6,7,8] Species of plants and animals and their relationships remain currencies of life: species are the focus of Aboriginal spirituality, comparable to the church and holy artefacts of Christian traditions. In this respect, support for management of biodiversity in an Aboriginal context may be seen as responding to the biocultural values highlighted in Chapter 1.

Among Aboriginal and Torres Strait Islander people are varied perspectives on the concept of biodiversity, just as in the wider Australian population. Many Indigenous people care strongly for their Country; others, however, may not express any views about biodiversity. Some are preoccupied with hardship, and others live in towns distant from their homelands. Still others pursue mining and mainstream economic opportunities without regard for biodiversity. Nevertheless the connection to biodiversity remains a widespread aspect of Aboriginal lives, as portrayed especially by artists from the bush and the city too. For example, in Melbourne Reko Rennie expresses his Gamilaraary ancestry in artworks of red kangaroo, echidna and other species.[18]

Indigenous artworks are rich in species, relationships and meanings. A painting by two Martu sisters of Karlamilyi (Rudall River) identifies 14 bush food and medicine species, six landforms, 26 places and six Dreaming characters. The painting asserts their family history and passion for these species and places. It stamps their authority to be recognised in decisions about land use.[19]



▸ ***Figure 6.7***: *Indigenous interests in country have been recognised to varying extents for more than half of Australia under different tenure regimes. Legal recognition of Indigenous rights and interests in land is a key driver of Indigenous land management.*[3] *Map prepared by Petina Pert, CSIRO.*


Declared IPAs in order of gazettal date:
1. Nantawarrina
2. Preminghana
3. Risdon Cove
4. Putalina
5. Deen Maar
6. Yalata
7. Warul Kawa
8. Watarru
9. Walalkara
10. Mount Chappell Island
11. Badger Island
12. Dhimurru
13. Guanaba
14. Wattleridge
15. Mount Willoughby
16. Paruku
17. Ngaanyatjarra
18. Tyrendarra
19. Toogimbie
20. Anindilyakwa
21. Laynhapuy - Stage 1
22. Ninghan
23. North Tanami
24. Warlu Jilajaa Jumu
25. Kaanju Ngaachi
26. Great Dog Island
27. Babel Island
28. lungatalanana
29. Angas Downs
30. Pulu Islet
31. Tarriwa Kurrukun
32. Warddeken
33. Djelk
34. Jamba Dhandan Duringala
35. Kurtonitj
36. Framlingham Forest
37. Kalka - Pipalyatjara
38. Boorabee and The Willows
39. Lake Condah
40. Marri-Jabin (Thamurrurr - Stage 1)
41. Brewarrina Ngemba Billabong
42. Uunguu - Stage 1
43. Apara - Makiri - Punti
44. Antara - Sandy Bore
45. Dorodong
46. Weilmoringle
47. Yanyuwa (Barni - Wardimantha Awara)
48. Minyumai
49. Gumma
50. Mandingalbay Yidinji
51. Southern Tanami
52. Ngunya Jargoon
53. Angkum - Stage 1
570
760
Kilometres
area:
ciated cultural

The successes in Indigenous resource management are patchy. They need to be strengthened, while being realistic about challenges resulting from socio-economic and educational inequities. Features that will widen the successes include the following:

- Support to Indigenous land and sea management sustained by Indigenous people
- Programs that help stimulate connections between Indigenous people and markets, creating employment and economic activity and reducing welfare dependency
- Indigenous-specific and multi-year funding based on local cultural knowledge, practices and time-frames
- Equitable, two-way engagement between Aboriginal people and scientists.[3]

On-ground solutions

Hands-on approaches are central to Indigenous natural resource management because many people have practical skills and prefer activities that take them regularly onto their Country. As Sandra and Peter pointed out, hunting is the rationale, tool and reward for managing land, while emphasising that hunting carries with it responsibilities to nurture the Country. Working with natural resources – notably hunting, gathering, fishing and burning – is especially necessary in Aboriginal minds for biodiversity conservation.

Martu rangers plan burns to protect populations of warru *(black-footed rock-wallaby,* Petrogale lateralis*) with staff of the regional land management organisation (Kanyirninpa Jukurrpa) and the Western Australian Department of Environment and Conservation. Photo: Fiona Walsh, CSIRO.*

Across remote Australia, the burning conducted by Aboriginal people is a major means by which biodiversity is manipulated.[20] Wildfire abatement and carbon sequestration through fire management provide vivid examples of beneficial Indigenous management.[21] Aboriginal observational skills and local knowledge also provide increasing potential in controlling weeds and pests. In deserts, springs and rock-holes are cleaned and fenced. In tropical and temperate regions, Aboriginal people want strong roles in decisions about water allocations so their resource and cultural needs are sustained as well as biodiversity. Income to support management is essential and so businesses based on natural resources, such as seed harvesting and carbon offsets, have some consistency with Aboriginal attitudes to biodiversity.

The most significant Australia-wide development may be the growth of Indigenous ranger groups. Since 2007 more than 83 such groups have formed, employing more than 660 individuals.[3] The initiatives have steadily developed capacity among rangers, especially through exchanges between traditional and scientific knowledge, and they deliver environmental as well as employment, economic and cultural benefits. Some Aboriginal groups incorporate cultural variables into their biodiversity assessments (Figure 6.8). Many ranger groups have taken up scientific tools such as Cybertracker and other hand-held data recorders for monitoring long-term change.

	KEY PARTS OF TARGET				
TARGET	LANDSCAPE/ SEASCAPE HEALTH	CULTURAL HEALTH	BIOPHYSICAL CONDITION	SIZE	OVERALL HEALTH
Wanjina Wunggurr Law - our culture	GOOD	POOR			FAIR
Right way fire	FAIR	FAIR	FAIR	FAIR	FAIR
Aamba and other meat foods	GOOD	FAIR	GOOD	GOOD	GOOD
Wulo	GOOD	FAIR	GOOD	GOOD	GOOD
Yawal	VERY GOOD	FAIR	GOOD	GOOD	GOOD
Bush plants	GOOD	FAIR	GOOD	GOOD	GOOD
Rock art	GOOD	POOR	FAIR		POOR
Cultural places on islands	GOOD	POOR	FAIR		POOR
Fish and other seafoods	GOOD	FAIR	GOOD	GOOD	GOOD
Mangguru and *balguja*	GOOD	FAIR	GOOD	GOOD	GOOD
Health of Wunambal Gaambera Country					FAIR

▲ ***Figure 6.8***: *Reports on monitoring now include biocultural targets and indicators of land condition. Here, the overall cultural and biophysical health of Country in the northern Kimberley is assessed to be 'fair'.*[22]

Conflicts can be associated with Indigenous use of biodiversity. Populations of some resource species were originally enhanced by Aboriginal activity, for example, provision of green pick for kangaroos through burning. However, with the introduction of guns and vehicles some species may be vulnerable to overharvesting. Hence, when hunting and gathering are decoupled from traditional management then the current threats and pressures causing declines may be exaggerated.

CONCLUSION

In recent decades, Aboriginal and Western approaches to biodiversity management have converged in some important ways. Indigenous Protected Areas and Indigenous land management organisations have led to expanded numbers of Aboriginal ranger groups and more Indigenous employment. More work is required to build upon these initiatives and to ensure that management of biodiversity will continue improving through incorporation of Indigenous views. The complementarity of Western and Aboriginal systems can lead to respectful two-way exchanges which are likely to give rise to locally driven, practical and more successful actions that maintain biodiversity or slow its decline.

FURTHER READING

Bohensky E, Butler J, Davies J (2013) Integrating indigenous ecological knowledge and science in natural resource management: perspectives from Australia. *Ecology and Society* **18**, 20.

Ens E (2012) Indigenous land and sea management in remote Australia. *Ecological Management and Restoration* **13**, 1–107.

Hill R, Pert PL, Davies J, Robinson CJ, Walsh F, Falco-Mammone F (2013) *Indigenous Land Management in Australia: Extent, Scope, Diversity, Barriers and Success Factors*. CSIRO Ecosystem Sciences, Cairns. <http://www.daff.gov.au/__data/assets/pdf_file/0010/2297116/ilm-report.pdf>.

Latz P (1996) *Bushfires and Bushtucker: Aboriginal Plant Use in Central Australia*. Institute for Aboriginal Development, Alice Springs.

Luckert MK, Campbell BM, Gorman JT, Garnett ST (2007) *Investing in Indigenous Natural Resource Management*. Charles Darwin University Press, Darwin.

Rose DB, Daiyi N, Deveraux K, Daiyi M, Ford L, Bright A (2011) *Country of the Heart: An Australian Indigenous Homeland*. Aboriginal Studies Press, Canberra.

Farming, pastoralism and forestry

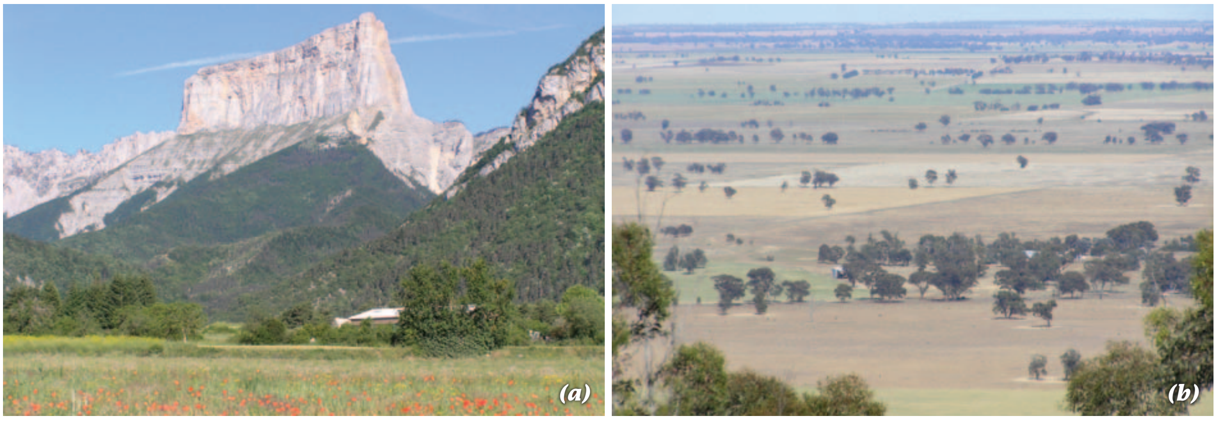
Sue McIntyre

Key messages

- Australian agriculture provides food and fibre (e.g. cotton and wool) for millions of people in Australia and around the world, as well as economic benefits, but it also alters environmental conditions. This has led to changes in species' abundance according to their tolerance of the changed conditions.
- Having evolved under dry, infertile conditions, most Australian plants and animals cannot survive the more productive and disturbed conditions of intensive agriculture and plantation forestry.
- Less intensive methods of agricultural and forestry production provide opportunities for the coexistence of native species, while enhanced biodiversity can in turn provide agricultural benefits in such systems.
- To retain most native plants and animals where intensive farming and forestry occur, these landscapes need to be embedded in larger areas of less intensive production as well as among areas of native vegetation that are managed for conservation.
- Biodiversity conservation in agricultural landscapes has been strongly driven by the voluntary actions of landholders, and continuing progress will rely on technical support, policies, legislative arrangements and financial assistance.

INTRODUCTION – THE EVOLUTION OF AGRICULTURAL ECOSYSTEMS

The distinctive Australian native biota is the product of three strong influences: a stable geological history, soils of low fertility, and a variable climate (see Chapter 2). Fire is also a feature of the landscape, and has been used by Aboriginal Australians since their arrival 50 000 years ago.[1] In contrast, the glaciated landscapes of Europe have experienced the grinding of ice against rock, forming young, mineral-rich soils, with a natural fertility well suited for cultivation. Further, human disturbances in Europe – tree clearing, urbanisation and soil cultivation – have been more intense, long-standing and varied.



***(a)** A glaciated landscape in the French Alps with farmland on the fertile valley floors. **(b)** In contrast, a typical farming landscape in south-eastern Australia with flat topography and old, weathered soils.*
Photos: Sue McIntyre, CSIRO.

Not surprisingly, from these two contrasting environments two broadly different floras have evolved: conservatively growing Australian natives adapted to eking out a living under limitations of water and nutrients, and the faster-growing European natives adapted to unpredictable destruction and rapid re-establishment.[2] While these two extremes typify the dominant environments of Australia and Europe, the spectrum of plant adaptations can be found in both continents.[3]

The development of European agriculture around 5000 years ago wrought large changes to local ecosystems, creating opportunity for species adapted to cleared and disturbed environments while causing the decline of others.[4] This history is now being repeated in Australia, but much faster and with a far greater environmental contrast and, therefore, more severe selection pressures. Modern agriculture and forestry have been introduced over a period of only a few hundred rather than thousands of years, so a phase of reassortment, retreat and extinction is taking place right now, and at a time when such changes are being documented by science.[5] Furthermore, the reassortment is occurring at the same time as the arrival of many non-native species already adapted to agricultural environments from Europe and increasingly elsewhere.

Additional pressure on local ecosystems stems from 20th century innovations in agriculture involving the intensive use of new kinds of inputs: fertilisers, non-native pasture species, pesticides and large machinery.[6] This 'intensive' agriculture has increased food and fibre production and with it prosperity, but our society is now realising that these benefits have produced a corresponding problem for biodiversity, raising the question: 'What are we going to do about minimising environmental harm?'

Not all agricultural and forestry systems are broad-scale, high-input and mechanised. This chapter examines different production intensities in Australia and their relationship to native biodiversity (Table 7.1). Circumstances are described in which the twin objectives of productivity for human uses and nature conservation might be met.

A HISTORY OF CHANGE, A SPECTRUM OF PRODUCTION STYLES

Aboriginal people practised a form of farming that manipulated the relative abundance of species, primarily through burning to modify or to protect vegetation in line with the values placed upon it.[7] But the technology imported along with European settlement was more varied than the firestick – domestic livestock, ploughs and, most of all, the many species that were brought to Australia.

This early depiction of Aboriginal hunting suggests the use of fire to create open areas and to flush game. Reproduction of Joseph Lycett, Aborigines using fire to hunt kangaroos, *circa 1820. PIC R5689, National Library of Australia.*

The continuum of production intensities established historically in Australia can still be found in different parts of Australia, and indeed some landscapes support more than one intensity (Table 7.1).

Table 7.1: The continuum of production styles found on Australian landscapes, from least to most intensive (left to right). Approximate differences in valued attributes are indicated by stars – the more stars, the greater the proportion of each attribute associated with that style

	Hunter–gatherer	**Firestick farming**	**Native pasture/ native forestry**	**Native–based pasture/native plantations**	**Intensive land use – cropping – non-native tree plantations**
Management aims	Harvest native species as encountered	Manipulate native species abundance	Manipulate native species abundance	Partially replace native species	Replace native species
Production	★	★	★★	★★★★	★★★★★★★★
Inputs		★	★	★★★	★★★★★★
Non-native species	★	★	★★	★★★★	★★★★★★
Native species	★★★★★★★	★★★★★★★★	★★★★★★	★★★	★
Ecological capital retained	★★★★★★★★	★★★★★★	★★★★★	★★★	★★

Production – *the amount of food, fibre and timber diverted for human use or completely removed from the system*

Inputs – *nutrients, energy and materials bought in from elsewhere for production purposes (e.g. fertiliser, lime, machinery, agrichemicals, crop seed)*

Non-native species – *the proportion of non-native species present in the system, deliberately or accidentally introduced*

Native species – *the proportion of native species persisting in the system*

Ecological capital retained – *the proportion of the sun's energy fixed by plants through photosynthesis (biomass) that is retained in the ecosystem, the rest being exported for human uses (via food, fibre and timber). This retained biomass can serve to maintain the ecosystem (e.g. through leaving enough vegetation to protect the soil from erosion or enough to burn to maintain desired species) and store carbon*

In Table 7.1 you can see that there are trade-offs among the different attributes. The more intensive styles have greater production, but require more inputs and tend to exclude native species and reduce the stability of the system, making it more vulnerable to extreme weather, erosion and invasion by foreign species. Less intensive land management requires fewer inputs and is lower in agricultural productivity, but supports more native species in greater diversity.

Within the broad production styles described in Table 7.1 are a range of land use types, which are described in the following section and summarised in Table 7.2.

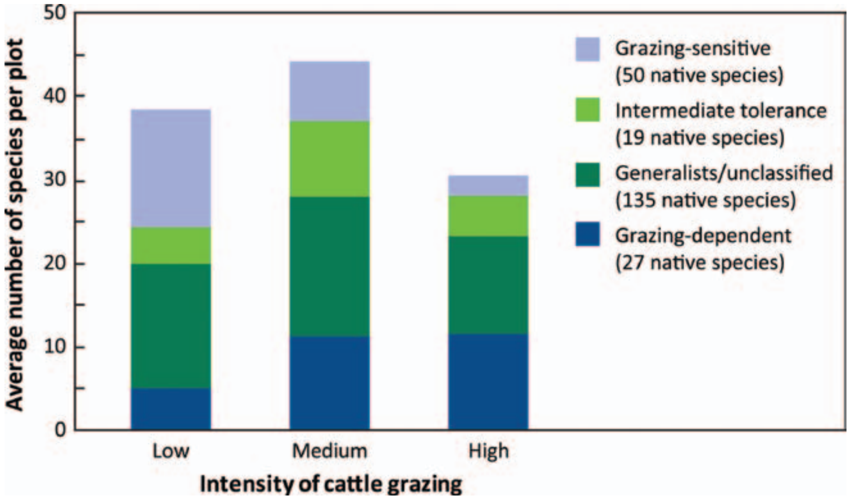
Table 7.2: Productive land uses and management to improve habitat quality for native plants and animals	
Land use	**Examples of options for increasing habitat quality for native species**
Low-intensity land uses	
Hunting and gathering/ Firestick farming	▪ Avoid overharvesting of native plants and animals ▪ Apply appropriate fire regimes
Rangeland grazing	▪ Conservative grazing ▪ Control selected non-native plants and animals
Native timber harvesting	▪ Maximise harvesting rotations ▪ Retain mature trees and fallen timber ▪ Control selected non-native plants
Intensive land uses	
Crops	▪ Avoid excessive use of fertiliser and pesticides ▪ Avoid soil erosion ▪ Leave vegetated area between crops and watercourses ▪ Retain mature trees and avoid cropping close to them ▪ Establish native trees around crops
Fertilised pastures	▪ Avoid excess use of fertiliser and pesticides ▪ Retain mature trees ▪ Do not apply fertiliser close to trees or watercourses ▪ Establish native trees in and around pasture
Plantation forestry	▪ Maximise harvesting rotations ▪ Retain stands of regenerating native trees and shrubs ▪ Leave thinned trees and pruned material on the ground

OPTIONS FOR RETAINING BIODIVERSITY WITHIN DIFFERENT LAND USES

Low-intensity land uses

In remote areas of Australia, traditional hunting and bush food gathering take place where Indigenous people still have access to their Country. This land use favours the persistence of the remaining native plants and animals although, with the introduction of guns and vehicles, some species are vulnerable to overharvesting. Burning by Aboriginal people can maintain suitable habitat for many native species. However, frequent fire may reduce soil cover and soil carbon, making land more prone to erosion. Different species within the same ecosystem may have different burning requirements. All these issues need to be taken into account in planning burning strategies.

Commercial grazing of native vegetation occurs in many parts of Australia, but is most widespread on native grasslands, shrublands and woodlands in semi-arid regions, called rangelands. Moderate levels of livestock grazing allow all but the most grazing-sensitive plant species to persist (Figure 7.1)[8] and leave a sufficient proportion of plant growth to provide food for insects, reptiles, birds and mammals, and enough plant litter to protect the soil from erosion and recycle organic matter into the soil.



◂ ***Figure 7.1****: Density of grassland plant species in three different grazing intensities. The species have been classified into four types based on their response to cattle grazing in subtropical native grassland. The histogram shows how cattle grazing causes shifts in the abundance of native species.*[8]

Overgrazing creates a downward spiral of pasture condition where trampling and reduced plant cover reduces soil condition and water infiltration, which further reduces plant cover.[9] As degraded soil is less productive, food supplies for both livestock and native animals are reduced. Overgrazing also alters the pasture, with most of the taller grazing-sensitive species being replaced by short-growing species, usually of lower productivity.[9] Large grass tussocks and shrubs can be lost, together with the insects, bird and reptiles that shelter and feed in them.[10] In many places in the rangelands, reduction in forage at the ground level can translate to lack of burning and thence to invasion of pastures by woody plants. With managed grazing, there is enough biomass remaining for fire to become a useful tool to reduce species that are unpalatable to livestock, so it can be useful for both biodiversity and pasture management.

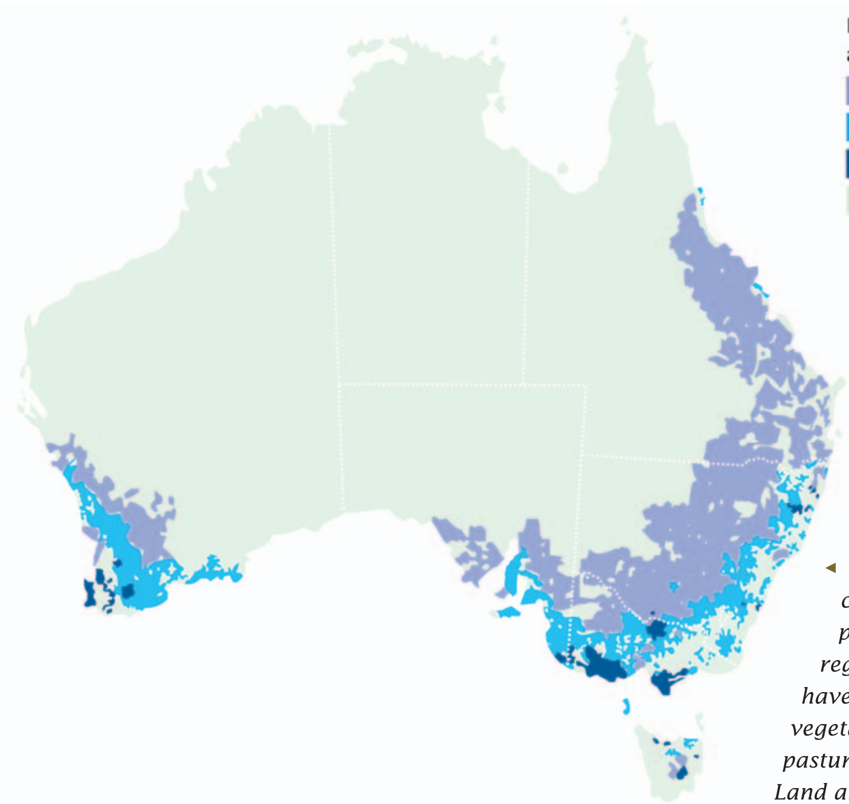
An additional task for the rangeland manager is the control of dingoes and wild dogs to protect sheep. However, the loss of these predators can allow kangaroo populations to flourish, which in turn can increase grazing pressure. It can also lead to higher cat density and negative effects on native mammals. Feral goats, camels, donkeys and horses also contribute to grazing pressure, so it is not simply a case of regulating livestock numbers to maintain an appropriate level of impact.

In the forested regions of southern Australia, harvesting of native hardwoods, *Eucalyptus*, and softwoods, *Callitris*, is another activity where moderate levels of exploitation can be compatible with maintenance of a diversity of species.[11] Economic pressures can lead to shorter harvesting rotations, which lower the average age of trees in the forest. Keeping some of the largest, most mature trees is important for native mammal conservation because they are rich in hollows that are needed for breeding. As for rangelands, small shifts in forestry practice can make large differences to the quality of habitat for native species (Table 7.2).[12] Controlling non-native species, and limiting the disturbances that encourage their proliferation, is good conservation practice, though not all non-native species have negative impacts, and some can even provide useful resources for native species.[13]

This cypress pine forest has supplied firewood and timber since the 19th century but still supports significant woodland birds and native flora. Note the cut stumps, young regrowth trees and large specimens of cypress pine and eucalypt, creating a variety of structures for wildlife. Photo: Sue McIntyre, CSIRO.

Intensive land uses

Only in the 20th century did industrial-scale intensive production systems spread over large areas of Australia, following replacement of draught mules, horses and bullocks by engines. Subsequent leaps in technology have included the introduction of legumes (e.g. clovers) combined with fertilisers to improve soil quality, and the use of chemicals to control weeds, pests and diseases. Better quality soils in the higher rainfall areas have generally been the most economically suitable for intensive uses, indicated by the map of fertiliser application (Figure 7.2). Parallel technical advances in forestry have enabled the establishment of single-species plantations with close management of nutrition, pests and diseases.



◄ ***Figure 7.2***: *Fertiliser use is concentrated in the higher rainfall parts of the continent, and indicates regions where intensive land uses have replaced much of the native vegetation with crops and fertilised pastures. Adapted from National Land and Water Resources Audit.*[14]

The intent of intensive production is to divert all the available plant growth resources either towards the crop of interest, or towards growing forage for livestock consumption. A successful intensive system, therefore, is one where the unproductive pre-existing native species are completely absent, and all non-crop or non-forage plants are excluded. Intensive production systems can generally achieve exclusion because, as discussed earlier, native plants are poorly adapted to high levels of disturbance and fertility.

Plantations are managed with the aim of producing even-sized trees, spaced to optimise growth, and with few other plant competitors. Photo: Willem van Aken, CSIRO.

Cereal growers aim to create an area of land supporting only the crop, with no weeds to compete for water, nutrients or light. Photo: CSIRO.

A pronounced feature of intensive systems is that they tend to leak nutrients, agricultural chemicals and soil into the creeks and rivers, and into the groundwater.[15] This leakiness can have adverse effects on native species in adjoining habitats and downstream from the source of nutrients.

The blue-green algae in this irrigation drain are indicative of nutrients leaking out of cropped areas and flowing into creeks and wetlands. Photo: Willem van Aken, CSIRO.

On the positive side, birds can benefit from an insect or grain bounty associated with intensive production areas, and kangaroos can benefit from nutritious food supply in, or near, fertilised crops and pastures.

Galahs, Eolophus roseicapillus, *benefit greatly from the food resources associated with crops and sown pastures, in this case the seed heads of non-native thistles, although they also need mature eucalypts with hollows to breed. Photo: Chris Tzaros.*

Where intensive production is economically profitable, it has led to dominance of the landscape by crops and fertilised pastures and, to a lesser extent, tree plantations.

Examples of intensive land uses dominating the landscape: ***(a)*** *cropping in the Riverina of New South Wales driven by the availability of irrigation water, and* ***(b)*** *radiata pine plantations near Queanbeyan, New South Wales. Photos (a) and (b): CSIRO.*

Such landscapes support relatively few native plants and animals, beyond those persisting in roadside vegetation and small nature reserves. Maintaining the health of mature scattered trees and managing for their eventual replacement is essential in intensive production landscapes, for both the survival and the movement of wildlife.[16] They also have aesthetic appeal, and provide shade for livestock. Without assistance they fail to recruit and eventually die out of the system.

(a) *Mature trees retained on land grazed for wool production provide critical habitat for birds and reptiles in a heavily grazed landscape. Note the lack of regenerating trees, and some tree death on the hill crest.* ***(b)*** *Trees remaining in fertilised crops and pastures are prone to die because of elevated nutrients and generally do not regenerate from seed. Photos (a) and (b): Sue McIntyre, CSIRO.*

Native plantings along the edges of paddocks allow some native birds to persist in cropped landscapes, but are not a complete substitute for the mature eucalypts.

Plantings in districts heavily cleared for cropping provide dense cover for birds but do not provide the hollows or quantity of food resources of mature trees. Photo: Wendy Henderson.

Tree plantations are monocultures managed to maximise growth through soil cultivation, added nutrients, and weed and pest control. Plantations support more native species than crops or sown pastures, but native plants do not thrive in any of these three habitats. There are ways of making plantations more biodiversity-friendly, however, including allowing stands of native shrubs and regenerating trees to remain, leaving thinned and pruned material on the floor of the plantation, and growing plantation trees to an older age.[17]

Mixed intensive production and rangeland-style grazing

In parts of Australia where a low proportion of land is suitable for cropping and fertilised pastures, we can see living evidence of the mixing of intensive and low-input land uses to achieve agriculturally productive landscapes that support a wide array of native fauna and flora. This biodiversity in return provides the ecosystem services of pollination and pest control. A common pattern is to locate fertilised pastures and crops on the creek flats and lower slopes of valleys, with grazing of native grassy vegetation on the sides of the valleys, and no livestock on the steepest, rockiest soils. This provides a fortunate mix of highly productive areas, bush for wildlife and native plants, and diverse, treed native pastures.

A common pattern of landscape use is to have intensive land use on the fertile valley floors (in this case, fertilised pastures seen on the foreground), grazed woodland on the slopes (mid-view) and forest on the highest parts of the landscape (the horizon). Photo: Sue McIntyre, CSIRO.

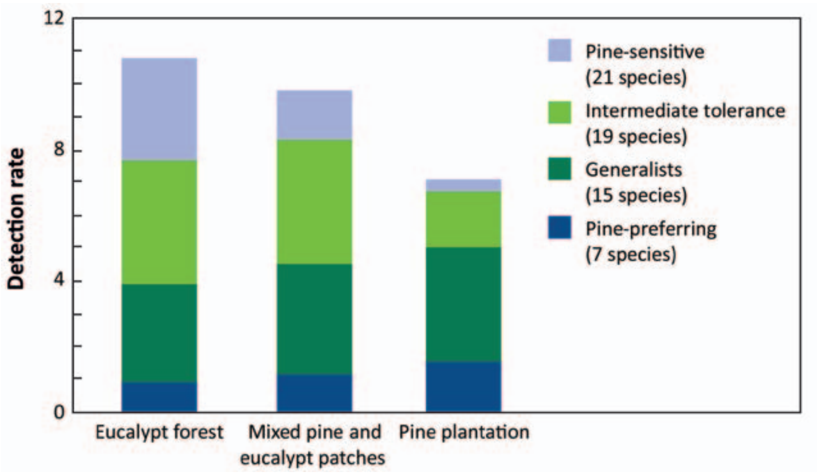
Many animals depend on treed watercourses and productive soils, so retaining or restoring native vegetation along creeks and rivers is needed to keep native fauna on the farm.[18] The way that native pastures are managed is also important. Retaining some trees is valuable for birds, and having a range of grazing intensities promotes native plant diversity.[19]

Riverside areas are important for wildlife, which benefits from the fertile soil and the presence of water, trees, shrubs and rocks. The diversity and numbers of birds are high when riversides are vegetated. Photo: CSIRO.

Mixed plantation and native forestry

Topography and soil quality can also drive the choice of location of plantations, which can be within a mosaic of native forest, some of which may be logged and some managed for biodiversity conservation. Such mixed land uses can collectively support a range of bird life, with a few native species even preferring pine plantations (Figure 7.3).[20]

Native fauna will further benefit from the management actions that produce a range of ages of trees in both the plantations and natural forests. The retention of mature trees, understorey species and fallen timber, and other techniques for creating mixed habitats, such as dams and cleared areas, will also encourage a greater number of species.[17,19]



▲ ***Figure 7.3***: *Numbers of species of native birds in eucalypt forests, mixed habitats, and pine plantations. The effect of habitat disturbance in the form of pine plantations on birds echoes that of cattle grazing on native plants (Figure 7.1); there are more species that are sensitive to the most intense disturbance than prefer it. However, unlike native grasses and medium-intensity grazing, there is no overall positive response by birds to intermediate disturbance (the mixed pine and eucalypt patches).*[20]

SOIL LIFE – THE DIVERSITY UNDERPINNING EVERYTHING ELSE

Regardless of the production style, the soil beneath it supports invertebrates, fungi and microbes, which form a significant component of the total biodiversity within an ecosystem. Algae, bacteria and viruses in soil are critical to the working of natural ecosystems and production systems, due to the essential role many have in nutrient recycling through decomposition, and a myriad of physical and chemical activities that keep soil in a suitable condition for plant growth. Different land use intensities affect the types of larger invertebrates and micro-organisms that persist – not all species tolerate cultivation, fertilisation or dry or infertile soils. Fungi are thought to be more important recyclers of nutrients where fertility is low, and bacteria more important in fertilised soils.[21] Apart from recognising the importance of organic matter for the health of soil, there is little practical advice yet available on the management of soil biodiversity.[22]

LANDSCAPE PLANNING OPTIONS TO RETAIN NATIVE BIODIVERSITY

The importance of amount and arrangement of habitat

There are two ways of enabling farming and native biodiversity to coexist. First are refinements to the management of the land, as mentioned previously and summarised in Table 7.2, to influence the *quality of the habitat* for different organisms. This approach focuses on maximising usefulness of the land to native species within the constraints of the particular land use, and minimising its unwanted off-site effects, such as avoiding nutrient leakage from a crop into a creek or area of native vegetation. Sometimes these refinements can be made with only a minor loss of income from production, but at other times there may be a major trade-off.[23] At times, the productive land uses that dominate many landscapes simply do not provide suitable habitats for the most sensitive species, in which case parts of that landscape may need to be managed specifically for nature conservation, not only in public reserves but also on private land.

The second approach is landscape planning, which can help determine the *amount of habitat* and adjust amounts and location of land uses across farming and forestry landscapes. The aim is to provide sufficient habitat suitable for native plants and animals to feed, breed, shelter and move around.[24]

The *arrangement of the different land uses* is also important.[25] Two land uses side by side can detract from each other's purpose or, at the other extreme, be of mutual benefit. Crops and fertilised pastures can be poor neighbours to bushland or creeks if excess nutrients wash into these areas and encourage natives to be replaced by weeds. Conversely, planting trees adjacent to crops and sown pastures can encourage some native birds to forage on the fertile areas and native insects to assist pollination, while also providing a safe retreat and breeding sites. But if the feeding birds are damaging the crop, their presence might be viewed differently by producers.

The need for plants or animals to move across landscapes has preoccupied ecologists for years. The term 'connected landscapes' has been coined in recognition of the need for organisms to move between different areas to meet the essentials of survival (see Chapter 5). Many animals and many more plants are unable to move from small fragments of bush across extensive cleared areas (Figure 7.4).

Habitat connectivity is the product of the amount of habitat, whether it is arranged in isolated fragments or one continuous strip, and the extent to which adjoining land use interferes with the way in which species can use the habitat. Generally, if a habitat covers two-thirds or more of the landscape, the species using it will be able to move around freely, regardless of the arrangement.[26] If the same habitat covered only one-tenth of the landscape, the connectivity would depend very much on the way that it was arranged. If it was in a single strip across the entire landscape, it would give a species the opportunity to travel a long distance, but this connectivity may not be adequate for the wellbeing of the species. For example, a narrow roadside strip of reserve with a minimal shrub layer passing through cropland may provide poor protection to small birds travelling along it from predatory birds that thrive in open areas.

▲ ***Figure 7.4****: The range of a native bird in an agricultural landscape.* ***(a)*** *A female brown treecreeper,* Climacteris picumnus*.* ***(b)*** *Tracked movements shown in yellow of a female brown treecreeper attempting to disperse. The dense cluster of points indicates where she was born. The mapped path shows the use of roadside and streamside corridors and scattered trees. The treecreeper reached another patch of vegetation to the north, but there were no treecreepers there so she ultimately returned home, and dispersal failed. Credit: Erik Doerr, Veronica Doerr, and Micah Davies.*

How much native habitat is enough?

The question for farm and landscape planning is: 'How much intensive production can take place without excluding most native species from the landscape?' Roughly speaking, if any land use that largely excludes native biodiversity (crops, plantations, fertilised pastures) covers less than one-third of the landscape, it is unlikely to lead to the disappearance of native plants and animals (Table 7.3).[19,27] Obviously the activities in the other two-thirds of the landscape are important in determining exactly which species thrive and which do not. Based on a review of the evidence, scientists have developed suggestions for the relative balance of different land uses across a landscape, known as the 10:20:40:30 guidelines.[17] They are summarised in Table 7.3 and Figure 7.5, and are based on the principle that a balanced range of land use intensities can provide a variety of landscape elements able to support the majority of local native species together with a range of human activities. The important underlying principle is that, regardless of how it is arranged, habitat covering two-thirds of the landscape is fully connected for all the species dependent on it, including those that are totally restricted to the habitat.

Table 7.3: Balancing production, habitat for native species and ecosystem function in different land use intensities.[27] Mobile species (e.g. most birds) cross unfavourable habitat; non-mobile species (e.g. many plants) require continuous habitat.

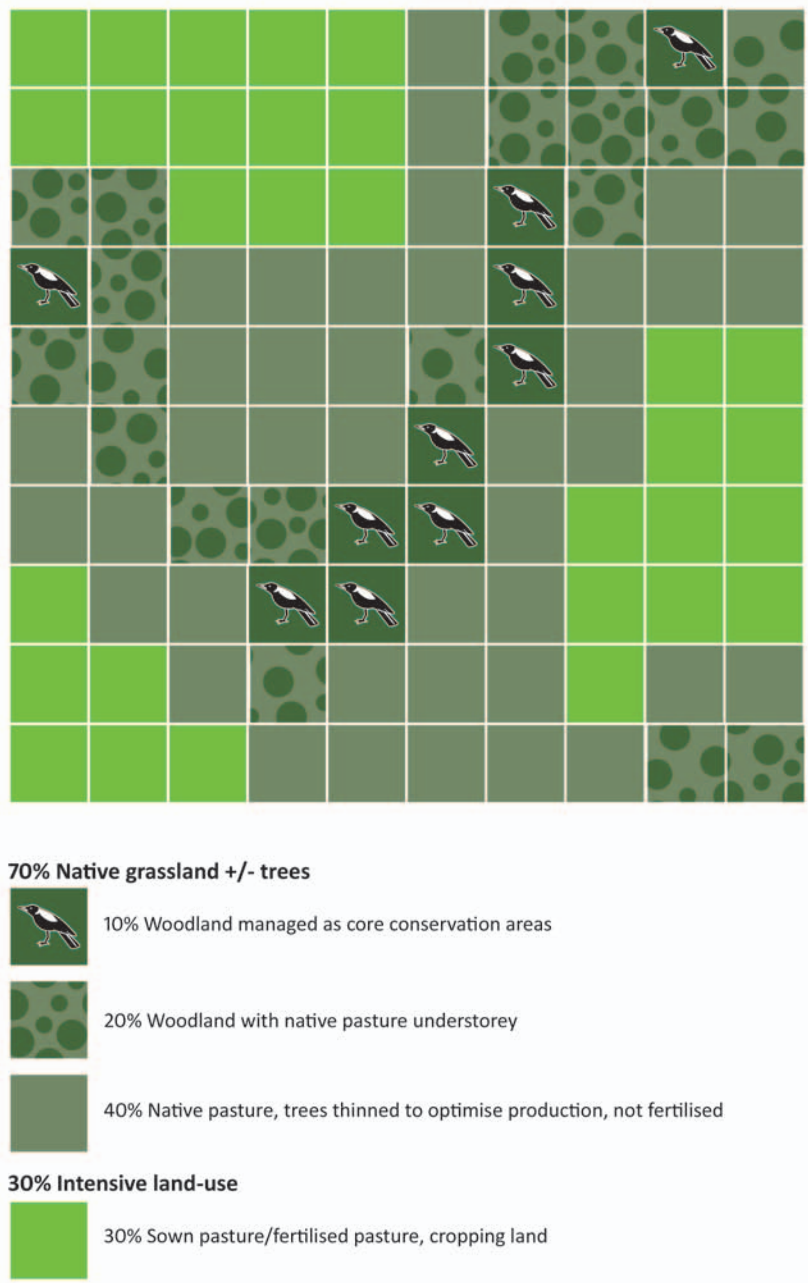
	Native vegetation – managed for conservation	Native vegetation – production uses	Moderate-intensity production	High-intensity production
Suggested proportion of landscape	≥ 10%	≥ 20%	0–70%	≤ 30%
Examples of land use	Conservation reserve, recreation area	Livestock grazing, native forestry	Native tree or shrub plantation, tree clearing to increase grazing production	Annual crops (cereals, vegetables), sown, fertilised pastures
Functions provided	≥ 70% of landscape covered with perennial vegetation			≤ 30% annual vegetation
Habitat provided for native species	Nearly all species, including those sensitive to human activities	Most species	Moderate number of species	Very few species highly tolerant of disturbance
Connectivity for non-mobile species	≥ 70% if ground layer is intact under moderate production; provides connectivity for most plants and invertebrates			≤ 30% not suitable for most plants and many animals to move through
Connectivity for mobile species	≥ 30% of landscape with trees and/or shrubs, providing connectivity for mobile species that require these elements for movement		Suitability will depend on species and land use	

Not all landholders are inclined or able to implement these guidelines. In recognition of this, several strategies have been developed by governments to encourage voluntary biodiversity conservation on private land (see Chapters 4 and 5).

ADOPTING NEW LAND USE PATTERNS AND MANAGEMENT

Societal change and voluntary actions

Awareness of biodiversity conservation among land managers has increased dramatically since the 1970s. The establishment of Landcare in the 1980s, and many other programs initiated by regional, state and federal governments, have continued to raise awareness. Increased two-way communication between researchers and land managers has helped more rapid dissemination of new technical knowledge, as well as providing realistic perspectives of the constraints and practicalities of biodiversity in production landscapes. We now see mainstream acceptance of biodiversity conservation in principle, although voluntary adoption of changed practices is not universal among landholders.



▸ ***Figure 7.5****: An idealised map of a grassy woodland property developed for maximum intensive land use and grazing but within the developmental limits for biodiversity conservation and provision of ecosystem services as described in Table 7.3. Land uses have been located so as to maximise connectivity for native plants and animals.*[8]

Legislative protection

Protection of individual threatened native species was the intent of earliest legislation, introduced progressively from the mid 20th century. As ecological understanding has evolved, the need to protect not only a range of species but also their habitats has become increasingly apparent. The financial rewards of agricultural development continued to drive the clearing of native bush, but at the same time the awareness of the environmental issues was gathering pace. In response, state and federal governments implemented vegetation and biodiversity protection

Programs such as Landcare have helped raise awareness of biodiversity conservation among landholders. Photo: Landcare Australia Limited.

legislation (see Chapter 3). Although necessary, regulations cannot solve everything.[28] For example, landholders may be reticent about revealing the presence of endangered species, or even eliminate them on their properties, fearing unwanted legal interventions. Other approaches are needed, as described next.

Regional land management initiatives

We are all responsible for determining the state of natural resources to be left for future generations and in many areas governments act on our behalf. Landscape planning to manage natural resources involves state and Commonwealth agencies, with responsibilities more recently being devolved to regional community groups. Planning and management may be organised around particular river catchments or threatened ecosystems. More recently, though, the scale has broadened to improving habitat connectivity between regions, where the long-distance movement of wildlife has been considered important (see Chapter 5).

Financial incentives

Implementation of landscape-scale guidelines presents significant and sometimes insurmountable financial challenges for primary producers, particularly in the most developed landscapes where reduction in the area of cropping land is rarely contemplated and where restoration has an uncertain outcome.[29] Financial subsidies to offset the cost of protecting particular habitats are applied directly or through tax relief. More recently markets have been used to change behaviour. One example is environmental auctions, contracts with government to protect vegetation at a particular site. Landholders bid for grants to improve conservation value, based on site condition, the proposed actions and the resources needed by the landholder.[30]

It comes down to us

Native species will survive best in farming and forestry landscapes when activities that continue to create positive long-term attitudes to biodiversity conservation are designed and implemented. Success depends upon continuing to find a balance between community values and involvement and individual decision-making, and appropriate levels of government intervention without leading to a reliance on it.[30] Many serious decisions affecting native plants and animals are everyday actions which superficially appear to have little consequence for conservation: the location of a shed, the decision to fertilise a lawn or paddock, the choice of plants selected from the nursery, or where heavy machinery is parked by the road. As personal awareness grows, it will influence the multitude of these small decisions, and may motivate us to tread more lightly on the landscape.

FURTHER READING

Dorrough J, Stol J, McIntyre S (2008) *Biodiversity in the Paddock: A Land Managers' Guide*. Future Farm Industries Cooperative Research Centre. <http://www.futurefarmonline.com.au/publications/other-publications.htm>.

Fisher A, Hunt L, James C, Landsberg J, Phelps D, Smyth A, Watson I (2005) *Management of Total Grazing Pressure: Managing for Biodiversity in the Rangelands*. Australian Government Department of Environment and Heritage, Canberra. <http://www.environment.gov.au/land/publications/rangelands-grazing.html>.

Gibbons P, Lindenmayer DB (2002) *Tree Hollows and Wildlife Conservation in Australia*. CSIRO Publishing, Melbourne.

Lindenmayer DB (1998) *The Design of Wildlife Corridors in Wood Production Forests*. Office of Environment and Heritage, Sydney.

McIntyre S, McIvor JG, Heard KM (Eds) (2002) *Managing and Conserving Grassy Woodlands*. CSIRO Publishing, Melbourne.

Pyne SJ (1991) *Burning Bush: A Fire History of Australia*. University of Washington Press, Seattle.

Rawlings K, Freudenberger D, Carr D (2010) *A Guide to Managing Box Gum Grassy Woodlands*. Australian Government Department of Environment, Heritage, Water and the Arts, Canberra. <http://www.nrm.gov.au/resources/publications/stewardship/bggw-handbook.html>.

Salt, D, Lindenmayer DB, Hobbs RJ (2004) *Trees and Biodiversity: A Guide for Australian Farm Forestry*. Publication 03/047. Rural Industries Research and Development Corporation, Canberra.

CHAPTER 8.

Cities and towns

Mark Lonsdale and Richard Fuller

Key messages

- Loss of natural ecosystems and of species is a fact of life in densely populated cities.
- Some species can prosper in an urban environment, but urban populations of species are generally too small to have a significant influence on their overall conservation status.
- Urban biodiversity is important nevertheless: it can build an appreciation among city dwellers of biodiversity and its conservation, enhance recreational space, and serve practical functions such as helping to cool the air and reduce stormwater and pollutant run-off.
- Visionary urban design can significantly improve the status and trends of biodiversity in cities and their surrounding regions.
- Australian biodiversity science has expended too little effort on the urban environment, and information on which to base urban biodiversity strategies is generally lacking.
- Supporting urban communities in Australia with information and monitoring tools will benefit biodiversity, and help connect Australians with the environment that sustains them.

THE CHALLENGE

One of the greatest triumphs of civilisation – the city – is also seemingly among the biggest challenges to the maintenance of biodiversity. Cities occupy just 2% of Earth's surface but account for 75% of the resources consumed by humans.[1] In 2007, for the first time in history, more people were living in towns and cities than in rural areas, and the proportion will continue to increase over the coming decades. In Australia, by far the majority (87%) of us live in cities and towns, and within the next 50 years 10–20 million more people will inhabit them.[2] Urban development is a major driver of environmental change: cities draw in energy, water, food and materials, cause pollution, destroy habitats as they expand, and introduce new species as pets and ornamental plants. On the other hand, cities can allow per capita energy demand to be reduced through the use of public transport and high-density housing, concentrating the population and reducing overall pollution and requirement for space and materials. Most importantly, cities are engine-rooms of cultural change, and focal points for resources and creativity. If the Australian community is to be engaged in solving the biodiversity challenges described elsewhere in this book, then the urban population will be an especially important part of that process.

The process of urbanisation has serious consequences for biodiversity. First, and most obviously, urban development permanently replaces natural ecosystems. Second, and perhaps more insidiously, isolation from the natural world leads to an 'extinction of experience' that transforms how people value the natural world around them – if people don't experience biodiversity, they will not value it.[3] It is a challenge to reconnect people with the nature that sustains them while concentrating the 'ecological footprint' of the human population into urban settlements.

Cities are shaped both by their environment and by their social and economic histories. These shaping forces are themselves changing, through such factors as water scarcity, carbon pricing, population pressures, and globalisation. When we try to manage biodiversity in urban environments, therefore, we are doing so in an environment that is itself continually changing. Cities are becoming ever more dynamic crucibles of intense and, in environmental terms, rapid change.

A city street gang: rainbow lorikeets, Trichoglossus haematodus, *in a tree overlooking Sydney's CBD. Human populations often occupy the places where biodiversity tends to be richest. Photo: Gary P. Hayes (http://garyphayes.com/photography).*

BIODIVERSITY IN CITIES

The economic and social benefits of urbanisation – the creation of employment and housing – depend on the permanent replacement of whatever ecosystem was there before. Plants and animals typically thrive in places where water is plentiful and soil fertility is high. Human populations also require those same conditions, and so inevitably end up occupying precisely the places where certain aspects of biodiversity are richest. Indeed, the fastest growing cities tend to be in areas where numbers of species are also naturally the highest.[4] The 34 global 'biodiversity hotspots' – areas particularly rich in species of importance for conservation – all contain urban areas.[5] This poses a direct threat to biodiversity; for example, as many as 8% of endangered terrestrial vertebrate species are at risk because of urban development worldwide.[6] Cities containing rich biodiversity occur all over the world, including Cape Town, Chicago, Curitiba, Frankfurt, Mexico City and Singapore. Half of South Africa's critically endangered vegetation types and approximately 3000 plant species native to South Africa are found in Table Mountain National Park in the Cape Town region, while more than 100 species never before seen by scientists have been discovered in parks and reserves in Singapore.[5]

Cities are also the entry point for many introduced species, which are known to be a major threat to biodiversity. Frequently, the majority of birds that city dwellers see are not native to the area. Non-native invasive garden plants, introduced to Australia by and for the urban population, make up most of Australia's 1953 agricultural and environmental weeds, comprising 70% of the total.[7]

There are many examples of threatened species occurring within cities. In western Melbourne, 44% of the area of native grasslands was destroyed or degraded between 1985 and 2005,[8] and several of the grassland ecosystems around Melbourne are currently listed as nationally threatened. Cities affect biodiversity not simply because they contain large numbers of people – the way that the population is distributed, the physical layout of the city, the housing density, the area of roofs and paving, and the location of parks and green corridors, can either moderate or intensify the impact of humans on biodiversity. At any given density or size of human population in an urban setting, we can sustain biodiversity by modifying these factors, which collectively are referred to as 'urban form'. This is analogous to the influence of different patterns of land use on biodiversity in agricultural landscapes (Chapter 7).

Occasionally, towns and cities can improve conditions for some species. Examples from around the world include the irrigation of desert landscapes during the growth of Phoenix, Arizona, increasing habitat heterogeneity in Finnish cities,[9] and elevated numbers of cavity-nesting bee species in cities worldwide.[10] Some urban habitats such as railway lines, abandoned industrial lands and urban wetlands can be rich in wild species and can play an important role in maintaining the biodiversity of a city.

Cavity-nesting bees, like this Megachile aurifrons *investigating a bamboo cane, can benefit from urban development. Photo: Marc Newman.*

On the other hand, species that thrive in urban environments are often abundant and widespread outside cities, so cities rarely contribute to conserving rare and endangered species. Often, the species flourishing in cities have a history of interacting with humankind, but species able to live close to people will partition the city habitats with those that need something closer to the natural vegetation of the region. For example, in the suburbs of Sydney, the birds living in parks and remnant vegetation are a different set of species from those occupying residential areas nearby (see Box 8.1).[11] One intriguing discovery is that, of the bird species colonising European cities, it is the bigger-brained ones such as pigeons that tend to be the most successful[12] – it is not just humans that need to be streetwise in cities! However, as the intensity of urbanisation increases even those species most able to prosper may eventually begin to show declines.[13]

WHY DOES BIODIVERSITY MATTER IN CITIES?

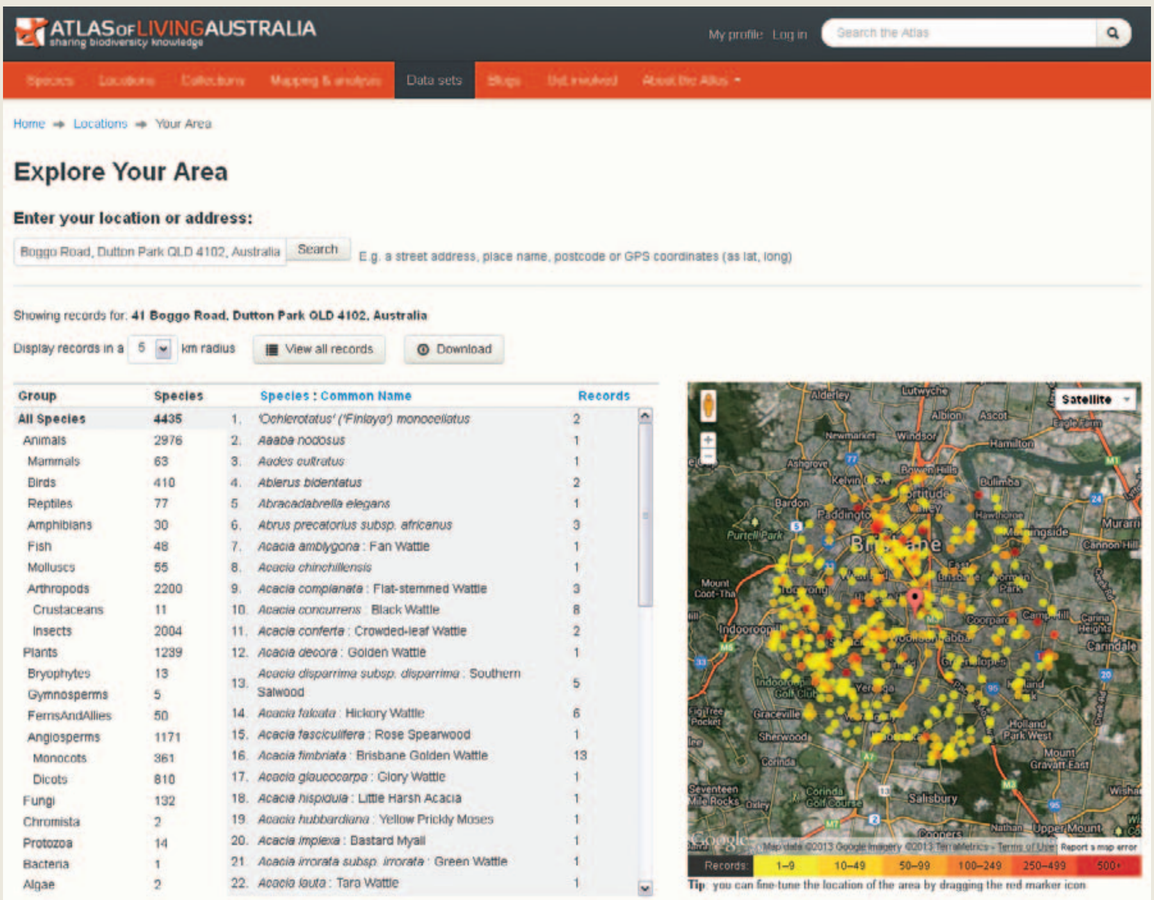
Australians should be concerned about biodiversity in cities first because of the value of the ecosystem services that it provides. Green spaces in cities can improve flood control by retaining and reducing stormwater run-off, saving money for flood control and protecting downstream natural ecosystems from the pollutants. Otherwise, built-up areas do not absorb rainwater well, leading to flooding by potentially polluted water.

Box 8.1: Explore Australia's urban biodiversity online

For people living in Australia's cities, it may not be obvious that there is a diverse range of plants and animals there as well. Use the *Atlas of Living Australia* to explore online the different species that are known to occur in your neighbourhood.

Through the 'Explore Your Area' function, simply enter your street address or location to display all known species-records within a 1, 5 or 10 km radius. For example, the address of the Ecosciences Precinct in the Brisbane suburb of Dutton Park brings up a list of 3432 different species within a 5 km radius (Figure 8.1). This connects you to occurrence records of plants, animals, insects and other life-forms, photos of the species, and more information on them.

You can engage in 'citizen science' by uploading your own sightings and photographs of species. You can contribute to science and give the scientific community access to data that it would not normally have. You will be building on the vast repository of data contained by the *Atlas* – currently about 40 million records. The information collected in the *Atlas* will help us to understand the status of biodiversity in Australia's urban areas and to analyse and predict trends over time.



▲ ***Figure 8.1**: The function 'Explore Your Area' in the* Atlas of Living Australia *lets users enter an address, place-name or GPS coordinates to find out what species occur in the area. Records can be filtered and downloaded for research, education or biodiversity management. Photo:* Atlas of Living Australia, *www.ala.org.au.*

Tree-planting and urban wetland renewal programs in Canberra are resulting in reduction in air pollution, stormwater interception and better flood management, and carbon storage.[5] The city contains more than 400 000 trees, constituting an urban forest that helps moderate the high temperatures associated with urbanisation, and in turn reducing the need for expensive and energy-consuming air-conditioning. The value of these services was predicted to reach between $20 million and $67 million in the period between 2008 and 2012.[5] Valuations such as these – where rigorously tested – help to highlight the contribution that urban ecosystems can make to the budget of a major city.

Having access to urban parks and green spaces has an important amenity value, influencing the physical and mental wellbeing of urban inhabitants. For example, access to a garden has been found to reduce sensitivity to stress, while a lack of access results in increased levels of depression and anxiety. Nearly 60% of householders in Perth felt that spending time in the garden was 'very important' or 'the most important' factor contributing to their overall wellbeing; further, it seems that the more diverse the green space, the greater the psychological benefits.[14] Since 2000, Parks Victoria, responsible for managing protected areas in Victoria, has been emphasising the benefits of visiting urban green spaces and other natural open spaces through its Healthy Parks, Healthy People program. The program promotes the idea that human health ultimately depends on healthy ecosystems.

There is another reason why biodiversity in cities matters. It matters because – as examples in the rest of this book show – our country's biodiversity matters, both to us and to the world. We are custodians of biodiversity for future generations, and, for many of us, biodiversity in urban areas

The simple act of gardening can help reduce levels of stress, depression and anxiety. Photo: Landcare Australia Limited.

represents the primary contact with the natural environment and our main means of connecting to it. Managing biodiversity in cities provides opportunities for many people to learn about and value it through activities in their own backyards and neighbourhoods, leading to novel planning and landscaping approaches to the urban form, and in turn to a reduction of negative impacts of cities on their surrounding environment.

There have been two broad approaches for reducing negative impacts of cities on biodiversity: directly, by actively sustaining biodiversity in urban areas; and indirectly, by reducing the per capita environmental impact of city dwellers (the environmental footprint). We next deal with these in turn.

SUSTAINING BIODIVERSITY IN URBAN AREAS

Growing and connecting green spaces

As cities grow, the opportunity for people to interact with nature depends increasingly on the availability of green spaces such as parkland, and less formal ones such as street plantings, backyards and gardens. In nearly 400 European cities, the proportion of urban green space *increased* with city area across the whole range of city sizes, from roughly 10% of the area in cities of 10 km^2 to 23% of the area in cities of 1000 km^2.[15] Clearly there are historical reasons why such cities had compact centres, but as European cities have grown, their green space networks are also relatively larger. It remains to be seen whether the same trend holds true for Australia.

Green corridors can promote the movement of species into and around urban areas. This one follows Kedron Brook through Brisbane's northern suburbs, just 6 km from the CBD. Photo: Fiona Brown, CSIRO.

The benefits of green spaces are not just a function of their size and number but also depend on their connection to other such spaces. There is increasing effort around the world to link up green spaces across a city, just as we saw earlier in the broader landscape (Chapters 4 and 5). Such 'green corridors' promote the movement of native species into and around the city, although care is needed to avoid moving non-native species in the other direction.[16] Revegetation is useful where the original native vegetation has been lost and where remaining vegetation is rendered isolated and degraded. Hundreds of community groups are engaged in such urban revegetation projects across Australia. By contrast, focusing on making larger green spaces without worrying about the connectivity between them simply increases the abundance of species already present in a given area, so we need to set aside habitat as well as make connections between such areas. Along these lines, new urban development strategies combine urban corridors (key development areas involving 10% of the city, for high-density living and public transport routes) with suburbs (90% of the city) that become areas of stability, with strict guidelines on development, renewable energy generation, stormwater collection and green space.[17]

The potential for biodiversity-friendly cities depends on being able to resolve opposing views about high-density living – the so-called 'compact city debate' (Table 8.1).[18] On the one hand, some advocates suggest that 'living green' is only possible in a low-density rural or semi-rural setting. This approach, however, would spread the harmful impacts of human settlements on biodiversity over a much wider area, as well as increasing dependence on transport. Opposing this is the view that creating high-density urban development will concentrate the negative impacts of development into small areas, leaving more land for biodiversity and agriculture, and favouring greener transport through economies of scale. With Australian cities already among some of the most thinly populated in the world, it will be important to understand the implications of these opposite extremes for the way our cities develop. A case study in Brisbane suggested that high-density compact design would minimise reductions in bird populations as the city continued to grow,[19] but can we reasonably ask people to live in more crowded conditions so that birds can have more space? We do need better information on how best a compromise can be achieved between individual human needs and environmental impacts under different patterns of urban settlement. The latest research indicates that urban planners will need to be thinking at the scale of the entire city and its surrounds if we are to minimise environmental harm from urban expansion.[20]

Table 8.1: Some arguments for and against high- and low-density cities

Arguments for high-density cities	**Arguments against high-density cities**
▪ Reduced habitat destruction through urban sprawl ▪ Reduced per capita resource use ▪ Green transport favoured ▪ Economies of scale for services	▪ Traffic congestion ▪ Overcrowding leads to 'escape to suburbs' ▪ Increased crime, poverty and ill health ▪ High-rise blocks discourage community life
Arguments against low-density cities	**Arguments for low-density cities**
▪ Greater area of destruction of habitat ▪ Invasive species introduced across broader landscape ▪ Increased car use ▪ Conservation managed haphazardly via private gardens	▪ Engagement of community in conservation ▪ Potential for much larger public green spaces ▪ Less congestion and less concentrated pollution ▪ Village-like community life

Two cities that are towards opposite extremes of urban density – top, Canberra, and bottom, New York City. Photos: Mark Lonsdale, CSIRO.

MAINTAINING REMNANT VEGETATION

The development of Australian cities has, of course, resulted in a significant loss of the original native bushland that had occupied the land. Nevertheless, there is still a significant amount of this 'remnant vegetation' in some cities. For example, 28% of the area of Perth's metropolitan region was remnant vegetation in 2003, while the figure was 13% for western Sydney, 16% for Melbourne's outer suburbs, and 12% for Adelaide.[21] This is a resource for species such as small native mammals, but it is also very susceptible to being converted to suburbs – between 1986 and 1993, at least 1600 km^2 of native vegetation was built on in areas around Australia's capital cities.[22] Its loss may be minimised by reducing low-density sprawl and maintaining green space and corridors.[21] Much Australian vegetation relies on periodic bushfires to regenerate itself, but of course it is very difficult to reintroduce fires into remnant vegetation that is surrounded by houses.

Engineered urban greenery: vertical gardens and green roofs

Techniques for adding greenery to buildings have become increasingly popular in cities around the world. Structures range from the 'green roof', in which a soil layer is added to a roof-top and planted with vegetation,[23] through vertical green walls fitted with vertical soil or non-soil structures that hold a variety of plants, to purpose-built green buildings that integrate living features into their design.[24]

This roof garden of drought-tolerant succulents and grasses is located on a commercial building in Melbourne's Docklands. Photo: Gardens by Fytogreen Australia Pty Ltd.

A vertical garden provides an attractive facade for a multi-storey car park in a large apartment block in Melbourne. Photo: Fytogreen Australia Pty Ltd.

Green roofs and walls are believed to protect facades against environmental extremes while becoming a new habitat for flora and fauna, and the technology is spreading fast. For example, in some parts of Berlin between 5% and 30% of the roof space is 'green', while Germany as a whole is adding about 1100 ha of green roofs each year. As with all emerging industries, setting quality standards for design and installation is a key issue.

Potential benefits from engineered urban greenery include stormwater management, reduction of the urban heat-island effect, and air quality improvement. While biodiversity benefits have also been claimed, supporting evidence for positive change is limited. Although engineered urban greening would not justify the clearance of vegetation in cities, such infrastructure can be used as a remediation tool in some of the most heavily urbanised areas. Unfortunately, retrofitting green infrastructure to buildings can be extremely expensive, and we still lack a sound basis for analysing the costs and benefits of such approaches to urban greening.

REDUCING THE URBAN ENVIRONMENTAL FOOTPRINT

Techniques have recently been developed to measure the ecological footprint of countries or cities, this being the amount of land required to sustain the lifestyle of an average inhabitant. The aim is to establish the biological impact that each dweller has on the wider landscape, mostly in terms of conversion of natural habitat for resource extraction and agriculture. For example, the findings of the Global Footprint Network suggest that each average human being requires 2.7 ha of land to sustain him or her. Australians generally require 6.6 ha per person; a person in East Timor has the lowest footprint on the planet at 0.4 ha; and the largest footprint is claimed by citizens of the United Arab Emirates at 10.7 ha per person.[25] We can use this approach to calculate the area required by a city to sustain its inhabitants (Table 8.2).

Table 8.2: Ecological footprints of various cities[25,26,27]

City	Population[27]	Average individual footprint (ha)[25,26]	City ecological footprint (km²)	City area (km²)[27]	Ratio of footprint area to city area
Sydney	3 956 000	6.6	261 096	2037	128
Washington DC	4 825 000	8.0	386 000	3424	113
London	9 576 000	4.9	469 224	1623	289
Beijing	18 241 000	2.2	401 302	3497	115
Tokyo–Yokohama	37 239 000	4.7	1 750 233	8547	205

This analysis shows that the population of Sydney requires over 260 000 km^2 of land to sustain it, roughly half the area of Spain, and about 128 times the geographical area it occupies as a city. Tokyo has nearly ten times the population of Sydney, but needs only seven times as much land to sustain its population because the average Japanese consumes less than the average Australian. Even so, the area of land required to support Tokyo – the city's ecological footprint – is five times the area of Japan!

The ecological footprint is usually calculated from the consumption of an average individual, but we can calculate an estimation of our own footprint using online calculators (e.g. the Victorian EPA footprint calculator[26]). The Australian Conservation Foundation has provided ecological footprint calculations for every Statistical Local Area across Australia and an online Consumption Atlas for querying this database by postcode.[28]

The two biggest opportunities for reducing the footprint of Australian cities lie in reducing demands on water and energy. Households use 70–80% of total urban consumption.[29] Australia's increasing urban population will have a growing demand for water. By the year 2050, scientists forecast that our largest cities will require 73% more water than currently; and, in addition, climate change will likely cause a reduction in supply to our major cities (e.g. around a 20% reduction to Melbourne's supply by 2050).[30] So our nation has its work cut out. Furthermore, to understand the full demand on water resources it is also necessary to factor in the water used in rural areas to supply food and fibre for city residents, as well as that used to generate electricity. The efficiency of water used in agriculture and power generation for cities is beyond the scope of this chapter, but it is dealt with in CSIRO's book, *Water: Science and Solutions for Australia* (see Further Reading).

PROGRESS REPORT: HOW ARE WE DOING?

Australian science has until recently largely ignored biodiversity in cities, and we lack the necessary data to allow comparison among different cities across the nation, or to compare our cities with those across the globe. A comparison of 20 of Australia's largest cities found that Townsville, Darwin, Sydney, Newcastle and Wollongong were the most favourable for biodiversity[31] (Table 8.3) – but this is a far cry from knowing how we should expand our cities in the future in a way that is most biodiversity-friendly.

The management of biodiversity in general suffers from a lack of standard measures (see Chapter 3), leading to a patchwork of trends that are not strictly comparable. Likewise, when measuring urban biodiversity we are viewing our cities through a blurry lens. For example, earlier we mentioned that 44% of native grassland areas were destroyed or degraded in Melbourne between 1985 and 2005;[8] the nearest comparable published data for Perth (Figure 8.2) show that remnant vegetation (including, but not confined to, grassland) declined by 23% between 1994 and 2003.[32] The vegetation categories and the time-frames, however, are different, so that we are left comparing apples with oranges. Such measures need to be developed not only so that we can make comparisons, but also as a means of learning what works well and can be more widely applied.

Table 8.3: Ranking of Australia's top ten cities in terms of potential to sustain biodiversity. Note that six are capital cities (Adelaide and Melbourne were ranked at 12 and 14 out of the 20 cities studied)[31]

City	Ranking of favourability for biodiversity
Townsville	1
Darwin	2
Sydney; Wollongong; Newcastle	3
Brisbane	4
Perth	5
Hobart	6
Gold Coast–Tweed; Sunshine Coast	7
Toowoomba	8
Cairns	9
Canberra	10

Australia's most recent State of the Environment Report[33] (Chapter 10, 'Built Environment') shows that more than 75% of residents in Australian capital cities feel they have access to a wide range of outdoor recreational environments, and that between 63% (Sydney) and 85% (Canberra and Hobart) of residents were satisfied with the natural environment of their cities. This is not very useful for knowing the state of urban biodiversity, however, because people may be satisfied with a low quality of natural environment – when it comes to objective measures of biodiversity itself, the data are simply not yet available. New ways of monitoring biodiversity are being developed, therefore, that can be applied to cities as well as to the broader landscape.

▲ ***Figure 8.2***: *Scientists are developing increasingly powerful image-processing techniques for monitoring biodiversity. This picture shows vegetation change in Perth between 2007 and 2009. The loss of trees is shown in red, yellow indicates no change, and green is an increase in tree cover. Grey areas have no vegetation. Source: CSIRO.*

CONCLUSIONS: THE WAY FORWARD

Highly urbanised countries often enjoy higher incomes and more stable economies, and cities generate a disproportionate share of a country's wealth. Consequently, cities are in a good position to achieve biodiversity conservation and pursue innovation in order to explore new ways of reducing environmental impacts. While biodiversity loss is a global concern, the local actions of urban populations engaging in biodiversity conservation within and outside cities can contribute to solving global problems.

Australian cities are continuing to grow – the population of Sydney is expected to double to about seven million people by 2056. The impact of cities on biodiversity, however, will not necessarily increase as fast as population growth if we plan this growth sensitively. In fact, this growth

More than 75% of residents in Australian capital cities feel they have access to a wide range of recreational outdoor environments. Photo: courtesy of Brisbane Marketing.

represents a great opportunity to do things differently. If we are imaginative and forward-looking, Australian cities could emerge as a contributor to the conservation of biodiversity, not only through parks and green spaces that are well connected to biodiversity across the broader landscape but also, more importantly, through support by city dwellers for national conservation efforts.

FURTHER READING

Cleugh H, Stafford Smith M, Battaglia M, Graham P (2011) *Climate Change: Science and Solutions for Australia*. CSIRO Publishing, Melbourne. <http://www.csiro.au/Outcomes/Climate/Climate-Change-Book.aspx>.

Gaston KJ (2010) *Urban Ecology*. Cambridge University Press, Cambridge.

McDonnell M, Holland K (2008) Biodiversity. In *Transitions: Pathways Towards Sustainable Urban Development in Australia*. (Ed. PW Newton) Chapter 16. CSIRO Publishing, Melbourne.

Prosser IP (2011) *Water: Science and Solutions for Australia*. CSIRO Publishing, Melbourne. <http://www.csiro.au/en/Outcomes/Water/Water-Book.aspx>.

CHAPTER 9.

Seas and coasts

Alan Butler and Nicholas Bax

Key messages

- Australia's marine biodiversity is globally distinctive but its dimensions are still being discovered. New scientific techniques are helping to describe marine biodiversity and manage it.
- It is hard to work out the biological processes taking place in the sea, but understanding marine connectedness is important for understanding the outcome of management. New automated sampling, monitoring and tracking, combined with large-scale managed intervention, provide the best opportunities for improved understanding.
- There are two big challenges in managing marine biodiversity: the scientific challenge of providing appropriate information, and the societal challenge of clarifying goals for management.
- Australia has developed a science-based participatory process for fisheries management within a clear legislative framework.
- Collaboration between scientists, managers and society is needed in order to manage biodiversity within the context of sustainable development.
- Australia is a respected participant and science collaborator in international marine management – for southern bluefin tuna, the management of Antarctic marine living resources, and the identification of ecologically significant areas on the high seas.

THE SCIENTIFIC CHALLENGES OF MARINE BIODIVERSITY

Australia has the third-largest Exclusive Economic Zone (the area extending 200 nautical miles from our coastline for which Australia has jurisdiction over economic and resource management) and extended continental shelf in the world (Figure 9.1). Our ocean territory contains a mega-diverse biota. In the north, Australian waters are adjacent to the Coral Triangle, the epicentre of marine biodiversity, and in the south the coastal waters contain species found nowhere else in the world's seas, with as many as 90% of some groups of organisms being endemic.

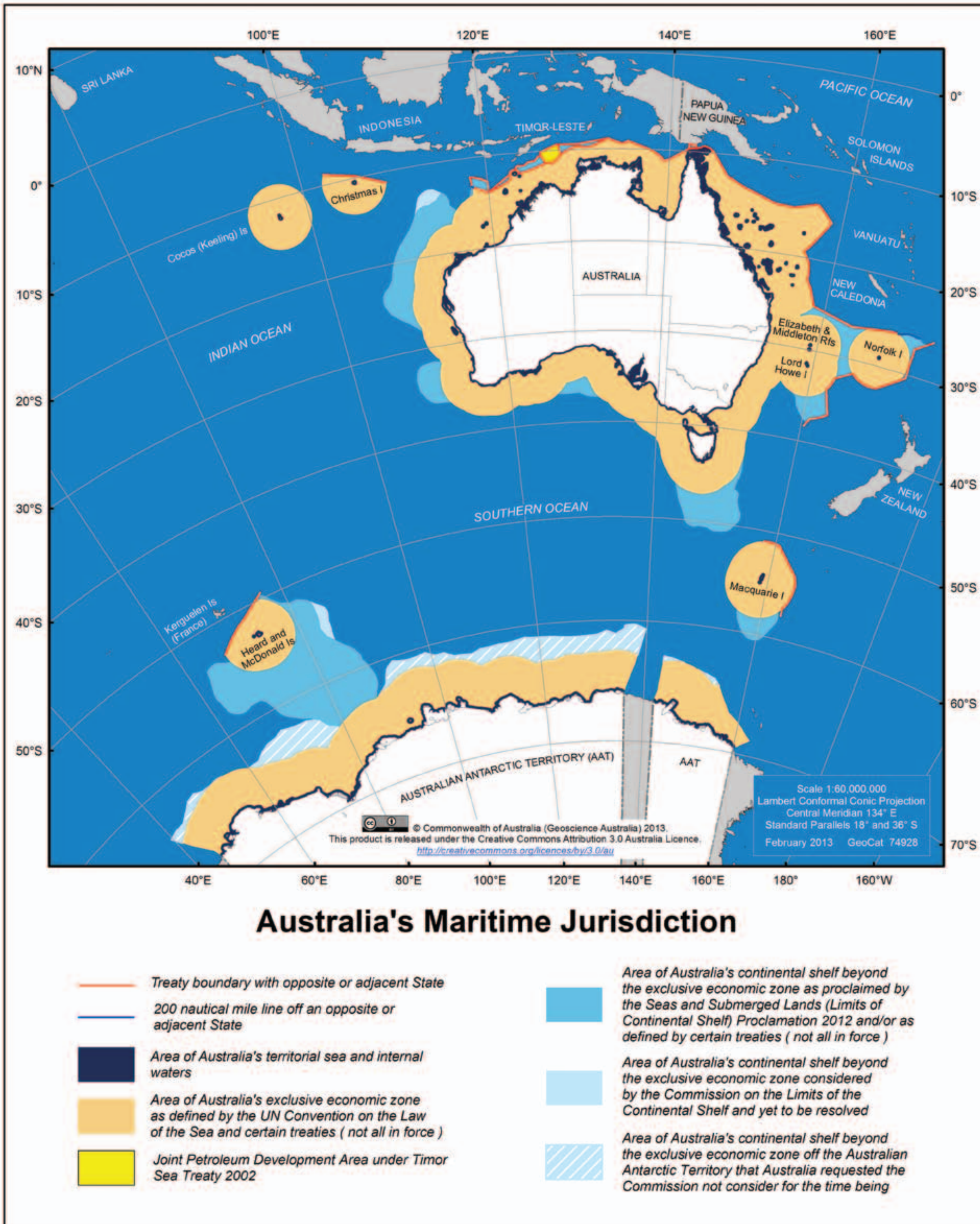
Exploration of Australia's marine biodiversity has been limited mostly to the margins of the continent, on the continental shelf and the upper continental slope. Even near the continent, some 50–70% of the species found in recent surveys have never previously been seen by scientists. Life originated in the oceans 3–5 billion years ago and even now 20 of the 33 animal phyla (the highest groupings within the animal kingdom) remain confined to them. The oceans are rich indeed, and Australian waters are among the richest.[1] Marine systems are distinctive, and so they often require different management and scientific approaches from terrestrial systems.

Discovering our biodiversity is exciting and absorbing, yet it is only a beginning if we are to understand what is going on in the seas. When we need to understand the ecological dynamics of the system, or even something as simple as how an organism grows and matures, then scientists need to go back to the same places more than once. Only recently has the technology become available to allow scientists to revisit a precise location a kilometre or more beneath the ocean's surface. Worldwide there are, not surprisingly, big gaps in our understanding of the oceans compared with the land.

Australian scientists are working broadly on two fronts to address these gaps. The first is to develop smarter ways of detecting and measuring biodiversity; the second is to improve our use of surrogates – things that are easier to measure than the species we really want to know about, but which still provide insight into the plant or animal of interest.

Smarter techniques

In the sea we explore biodiversity using many tools. Among them are robots – moored sampling devices, Argo floats and gliders (Box 9.1). These have revolutionised our physical understanding of the oceans, and now biological sampling capacity is being added to these robots by fitting cameras and other biological sensors. An even more exciting aspect of sampling in the sea (and elsewhere) is to examine the genome of a whole group of organisms at once – a process called metagenomics. This is especially valuable – and virtually the only way – when it comes to micro-organisms. Genomic techniques can tell us not only about diversity in organisms too small to see, but also about diversity in ecological processes. As one example, scientists are defining the roles of different kinds of micro-organisms in nutrient cycles in tropical estuaries, which in turn affect



▲ ***Figure 9.1***: *Depiction of the various zones and limits, under the United Nations Convention on the Law of the Sea, that comprise Australia's marine jurisdiction. Source: Geoscience Australia.*

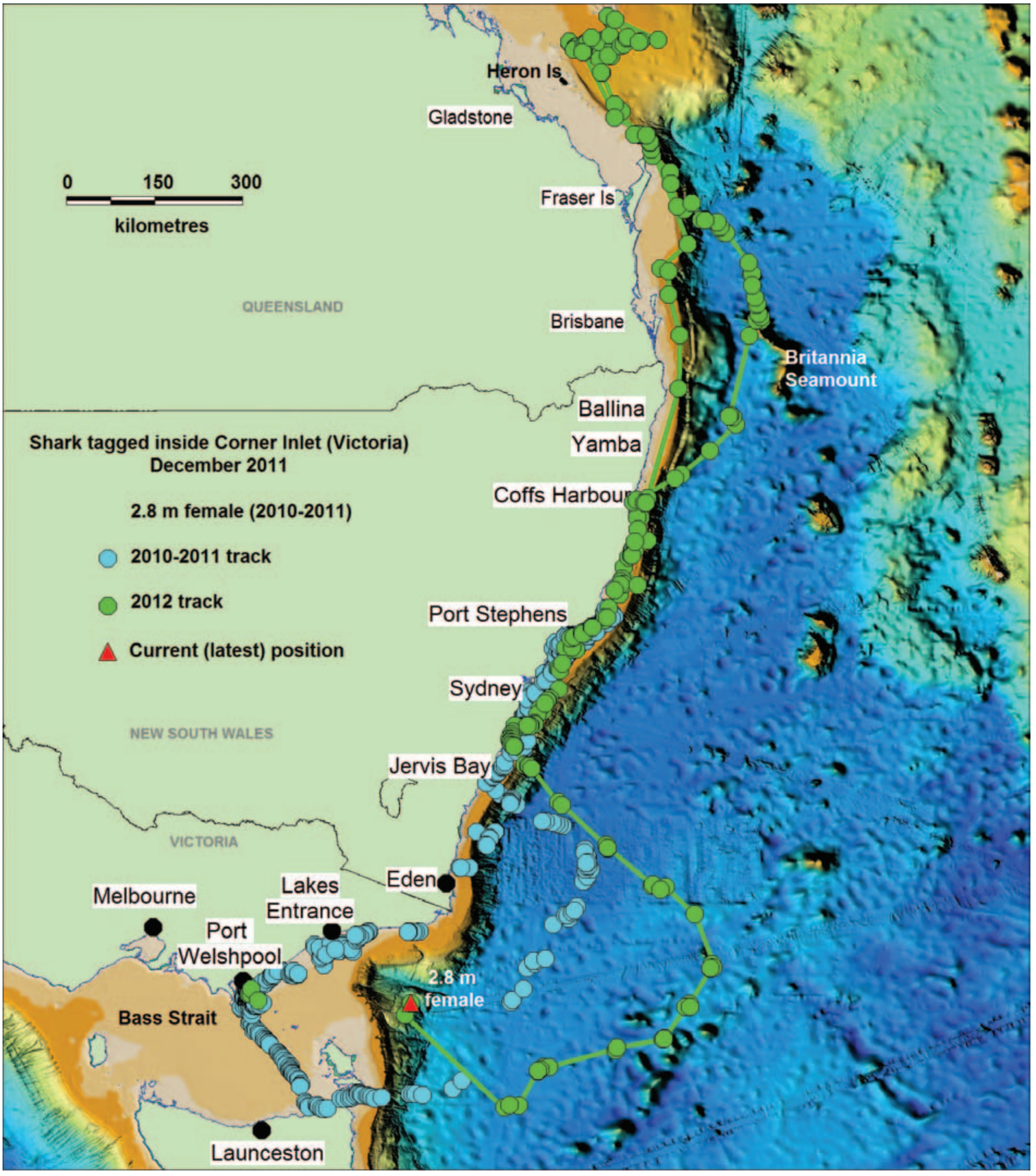
the amount of nutrients washing out onto coral reefs. They find a high diversity of microbial types but, unlike the picture for more complex organisms, genomics suggests that the micro-organisms in Australian waters tend to be similar to those found elsewhere in the world.

To unravel how diversity relates to ecological function, much broader coverage is needed, but the difficulty is to obtain enough genomic samples. Ship-based, manual sampling is expensive; robots would reduce sampling and assay costs. There are several engineering challenges to be overcome to make and miniaturise such devices, but we anticipate that these will be solved in the next few years.

Older technologies such as acoustics (what used to be called echo-sounding or sonar) continue to evolve to make increasingly sophisticated measurements. Another powerful example is the technology of global positioning systems. Animals can now be tracked across expanses of ocean, the tracking devices even reporting back the conditions as they travel (Figure 9.2).[2]

Scientists are also producing better products from their data to facilitate management and public understanding. For example, ocean currents around Australia are now routinely predicted and made publicly available by BLUElink.[3] Furthermore, the southern boundary of the east coast long-line fishery is determined weekly using these data, to reduce by-catch (the organisms caught unintentionally while fishing for other species). Also, the introduction of the Integrated Marine Observing System (Box 9.1) has greatly enhanced Australia's marine data collection, management, and dissemination.

Releasing a great white shark from the sling after tagging. A blue satellite tag is visible on the dorsal fin; there is a conventional plastic 'spaghetti' tag on the flank (which cannot be seen), and the shark also has a long-life acoustic tag (battery life about seven years), which has been surgically implanted under its skin. Photo: Justin Gilligan.



▲ ***Figure 9.2**: Track of a 2.8 m great white shark,* Carcharodon carcharias, *tagged in Corner Inlet, Victoria, over two years. Source: CSIRO.*

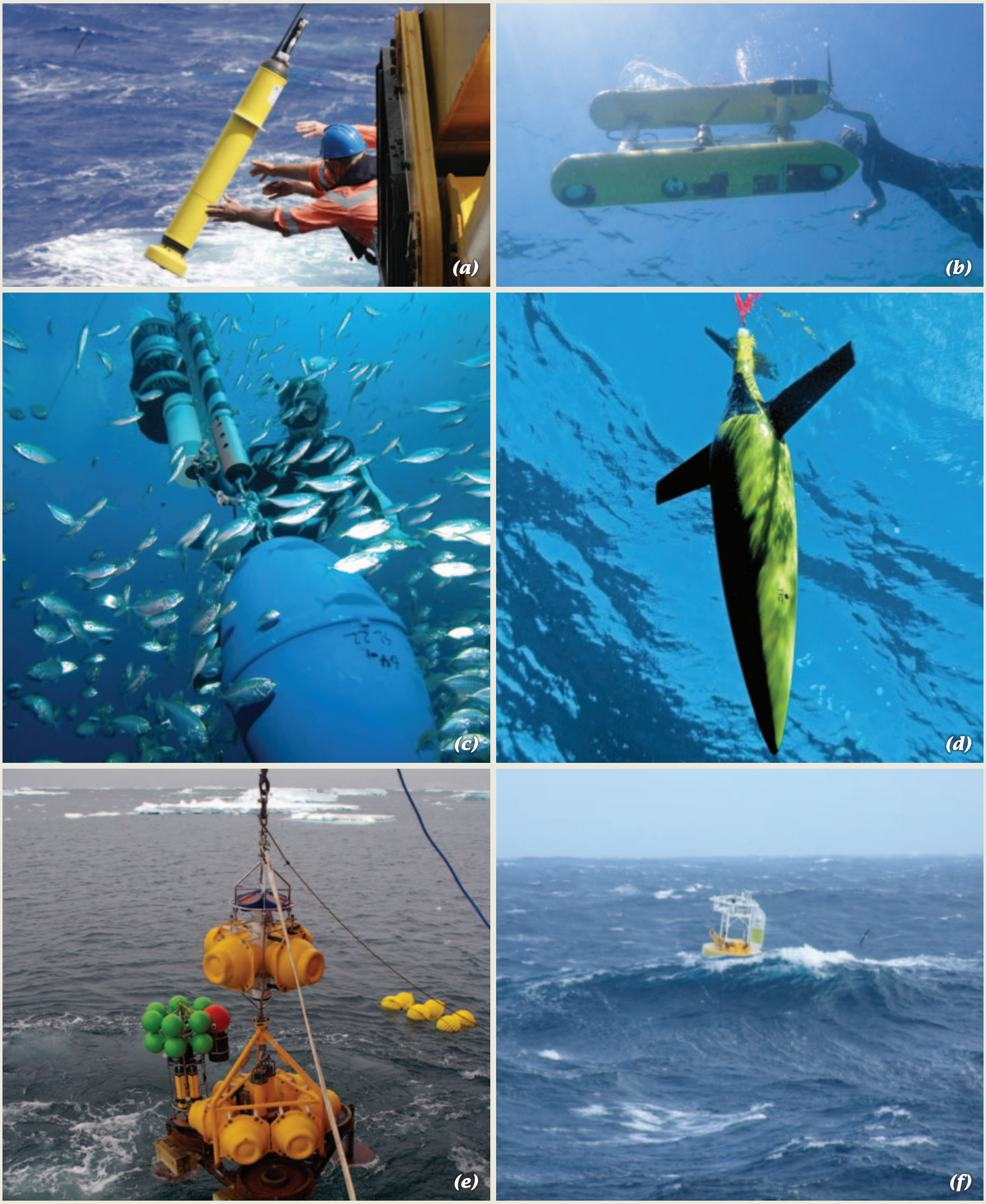
Box 9.1: Australia's Integrated Marine Observing System

The introduction of Australia's Integrated Marine Observing System (IMOS) is an especially exciting development.[4] In just a few years, IMOS has established a network of observations – mainly physical but increasingly biological as well – around the nation's oceans, and a system for managing and making available the huge amount of information (Figure 9.3).

▲ ***Figure 9.3**: An illustration of the data streams being collated by IMOS. Yellow dots, Argo floats; pale blue lines, ships of opportunity (i.e. commercial vessels carrying freight or passengers but which take scientific measurements); dark, olive and white lines, research vessel tracks; orange lines, elephant seal tracks. Source: IMOS.*

At the IMOS web-portal you can find data using a map interface, or by searching the database.[5] For example, the latest seal-tracking results are available; associated with those tracks are data on temperature, salinity and depth, as well as the animal's location and time. From the tags we learn amazing amounts about the biology of the seals – how deep they dive, how far they travel, where they feed. As a bonus, because they go regularly to places we find difficult, such as under the Antarctic sea-ice, we get valuable data for the physical oceanographers. You can also find the tracks of robotic devices called 'ocean gliders' – these are already measuring some aspects of biology as well as a suite of physical measurements, and more biological results will surely come. These are a few examples; we now have a wide range of new tools, and marine ecology is just starting the sort of revolution that has made so much difference to other fields of endeavour, such as physical oceanography and climate science, in recent decades.

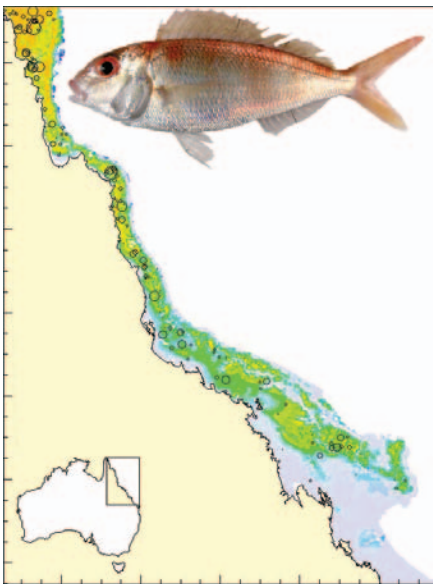
Elephant seal, Mirounga leonina, *with a conductivity–temperature–depth tag. As well as learning about the biology of the seals we are getting more data from inaccessible places, such as under the sea-ice in Antarctica, than ever before. Photo: Chris Oosthuizen, IMOS.*



Sampling devices used within the Integrated Marine Observing System. ***(a)*** *Argo float deployment;* ***(b)*** *autonomous underwater vehicle;* ***(c)*** *acoustic receiver mooring;* ***(d)*** *ocean glider;* ***(e)*** *polynya ocean monitoring;* ***(f)*** *Southern Ocean flux station buoy. Photos: (a) Alicia Navidad, CSIRO; (b) Kim Brooks, AIMS; (c) Rob Harcourt, Macquarie University; (d) Daniel Wisdom, AIMS; (e) Steve Rintoul, CSIRO; (f) Eric Schulz, Bureau of Meteorology.*

Surrogates

Planning and management of the marine environment and biological discovery must work hand-in-hand. Some of the sea's physical features – depth, bottom hardness, water temperatures and nutrient concentrations – can be mapped relatively rapidly at a scale of square kilometres or more. We already have more detailed information about some organisms (such as fishes) than about others (e.g. bryozoans). To get around the knowledge gaps, scientists are developing biodiversity surrogates. Can the patterns in the distributions of fishes indicate the sorts of patterns found in some kinds of invertebrates? And can some clever combination of physical variables at a particular place – depth, temperature, current velocity, or type of sediment – predict the sorts of organisms that would be expected there? Sophisticated statistics on large data sets suggest that the answer is 'yes, but …'. These approaches can work under specific conditions and scales, with an important aspect of uncertainty and probability in the predictions. But surrogates are just that, and do not directly mimic the biology of organisms or measure their abundance. Surrogates might predict where conditions are suitable for a particular fish, but they won't tell you if the fish are suffering from over-fishing, or a disease, or are absent due to some other as yet unknown ecological factor (Figure 9.4). Surrogates also miss historical or evolutionary factors, such as why penguins don't occur in the Arctic.



▲ ***Figure 9.4**: Distribution of rosy threadfin bream,* Nemipterus furcosus*, on the Great Barrier Reef shelf of north-eastern Australia. The black circles show abundance as measured from fishing samples. The colours show predicted distribution of threadfin bream, with blues and greens indicating low, yellow indicating medium, and red indicating high biomass. Ecological explanations for these patterns are still developing. Source: CSIRO.*

Surrogates have been important in the design of the recently proposed Commonwealth Marine Reserve network. While they offer exciting possibilities, surrogates cannot replace direct knowledge of an ecosystem. Surrogates can be used to predict and map how the present environment affects the distribution of organisms and how those distributions might change in the future, but they cannot provide the basis to measure real distributions and determine changes over time – actual field observations are required for this.

THE DYNAMIC NATURE OF MARINE BIODIVERSITY

Biodiversity is dynamic – it's a set of processes as well as being a list of species, genes or ecosystems. Despite the technical difficulties, we are learning a lot about these processes in the sea, and some highlights are mentioned here, concentrating on the idea of 'connectivity'.[6]

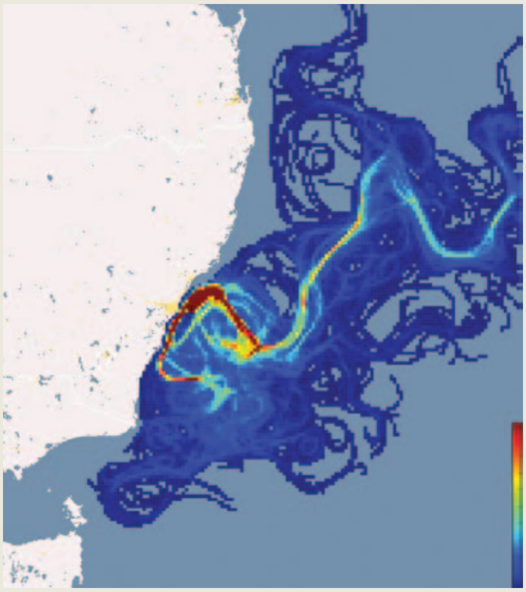
The oceans are well connected. Ocean currents move water, oxygen, nutrients, heat and species continuously around the globe. Connectivity is an ecologically complex concept (see Chapter 5) but connectivity in the sea has many advantages: biodiversity depleted in one area may be recolonised with offspring from another; point-source pollution like oil spills can be mobilised by the energy in the oceans, diluted by the movement of the oceans and finally broken down by the organisms that live there; animals that are stationary as adults can filter food particles from the moveable feast that bathes them; while animals that are mobile can take advantage of different habitats at different times in their lives.

Some areas of the sea are disconnected, however; low connectivity allows pollution and nutrients to concentrate and may lead to 'dead zones' in the oceans where oxygen is consumed as soon as it arrives. Some potentially mobile species are highly restricted: some shallow-water skates have been restricted to small 'habitat islands' for hundreds of thousands of years. Less mobile species are more vulnerable and are increasingly experiencing competition and predation from more mobile species that are responding to the warming ocean waters.

Animals that ride the currents have to deal with speeds of flow and directions that can change daily, seasonally and between years, making it uncertain whether they will ever make it back home. That is why almost all the offspring of the majority of marine species die, leaving the continuation of the species to depend on the very rare offspring (or two) that make it back to where their parents started the process. This leads to great variability in the number of animals produced each year – a real challenge for fishery managers (Box 9.2).

Box 9.2: Connectivity and biological variability

Physical and biological oceanographers work together to understand patterns of water movement in the oceans and their effects on biology. For example, the tropical rock lobster in Queensland and Torres Strait, *Panulirus ornatus*, circumnavigates the Coral Sea as a series of larval stages, carried by the currents. The variable behaviour of the currents makes a big difference to lobster recruitment (the number of young animals joining the fishery each year). There have been serious recruitment failures in recent years for the western and southern rock lobsters, *Panulirus cygnus* and *Jasus edwardsii*, leading to severe reductions in the catch. The lobster's life-cycle is so complicated that no one is sure of the reason for the recruitment failure, but it probably has something to do with ocean currents.[7] Biologists and physical oceanographers are working together to model the movements of ocean currents and, hence, how they might carry larvae. You can find, and use, an example called Connie at www.csiro.au/connie2/ (Figure 9.5).



▸ ***Figure 9.5****: Output from the connectivity modelling system Connie, showing predicted movement over 60 days of particles released 40 km east of Sydney. This illustrates how broadly organisms that drift as plankton can disperse with the currents. Colours indicate percentage of particles that passed through each point (scale max. 20%, min. 0%). Source: CSIRO.*

Shifting baselines: a complex game with changing rules

With climate change, the ocean environment isn't stationary. There have always been, of course, short-term changes and cycles – storms and calms, El Niño and La Niña years – but longer-term changes are now evident, both in physical environment and in biological interactions. Weather patterns are changing, ocean acidity is increasing, ocean currents are changing, and (to cite an example from only one part of the Australian coast) many species of macroalgae, microalgae, zooplankton, invertebrates and fish are extending their ranges southward down the east coast (Box 9.3).[8,9,10] But ecosystems don't move as a collective; rather, different species move at different rates and in different directions, and the complex interactions in ecological communities are frequently unpredictable.

The concept of 'novel ecosystems' is increasingly discussed (see Chapter 4). All ecosystems are now to some degree new due to the effects of climate change and invasive species. More than 170 introduced marine species have colonised Australian waters. In heavily used locations such as Port Phillip Bay, non-native invasive species are now more abundant than natives. Non-native species arrive via oil rigs, commercial shipping, recreational yachts and fishing nets, and most established species are here to stay. An estimated 10 000 species are in transit in ships' ballast water around the world at any one time. With more than 5000 international ship visits to Australia per year, a number projected to double by 2020, this will continue to be a challenge to managers. The reality of shifting baselines has important implications for setting goals and objectives.

Box 9.3: The long-spined sea urchin in south-eastern Australia

The New South Wales sea urchin, *Centrostephanus rodgersii*, has been extending its range down the east coast for some years and is now established off Tasmania, where it is having major effects. The complex story is not yet fully understood, but contains these elements.[6,7]

- Larval urchins float in the East Australian Current, which is now carrying warm water further south, allowing adult urchins to arrive in Tasmania.
- Urchins eat kelps, and can change the habitat to 'barrens' dominated by encrusting coralline algae.
- Abalone (important seafood #1) eat kelps, either directly or by catching drifting algal fronds, and don't do very well if there are extensive barrens.
- Large rock lobsters (important seafood #2) can eat urchins and may be effective in keeping urchin numbers down, but large lobsters are being selectively fished out of the system.

There is a good deal of research being done on this problem, including management of the fishery for lobsters in the hope that they will reduce urchin numbers. But the problem is complex, and there will be many others like it in the future.

DECIDING WHAT MATTERS AND WHAT TO DO ABOUT IT – A SOCIAL CHALLENGE

The first strength of science lies in describing the state of things and what is causing change. Science can also describe management possibilities. In the end, though, looking after 'ecosystem health' can only be achieved in the context of societal goals. Deciding what matters ultimately requires stakeholders, managers and scientists working closely together and communicating with the general public, to decide what in the oceans is important to us humans.[11] The challenges in understanding and caring for marine biodiversity may now be summed up as follows:

- The scientific challenge of providing appropriate information under conditions of uncertainty
- The societal challenge of clarifying goals for management when there is ambiguity and lack of consensus among the players.

To deal with both challenges it helps to adopt an 'adaptive management' approach. Adaptive management is a systematic process to improve decision-making in the face of uncertainty. The process involves a cycle of planning, taking action, evaluating the results of the action, and then taking further action based on the results of that evaluation. In the following section we discuss a few key issues in marine biodiversity where progress is being made using this approach.

Fishing and ecosystem-based management

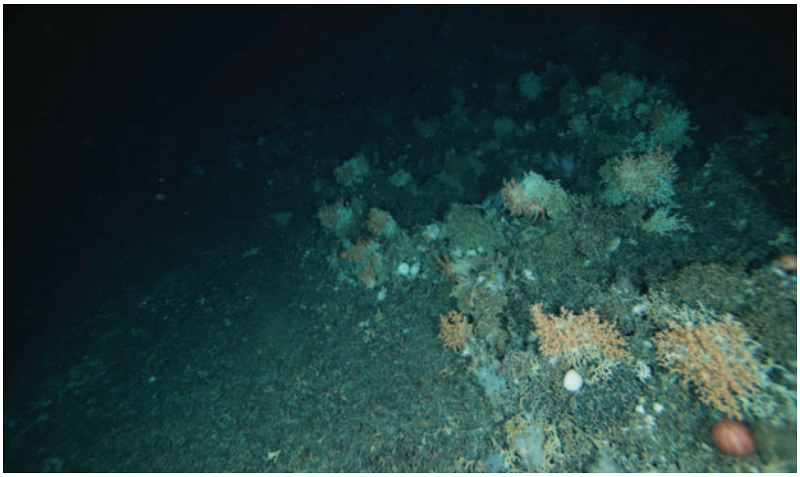
Of the many human impacts on marine biodiversity, the biggest single direct effect stems from fishing. However, it is also an encouraging story. The magnitude of the effect of fishing has encouraged research, invention of creative ideas and, in Australia at least, significant management interventions. Successes in the arena of fisheries management are now informing advice for managing biodiversity more generally.

Traditional management of fishing naturally concentrated on the target stock, including more recently potential loss of genetic variation within it. But fishing has effects on non-target biodiversity too, by inadvertently catching them, by physically altering habitats and damaging animals attached to the seafloor, or indirectly through removal of top predators so that some species lower in the food chain become more abundant. In the low productivity deep sea, recovery may take decades or centuries, well beyond the traditional management cycle. However, such effects are not to be assumed, and the results of each investigation are not necessarily as expected.

The cooperative system of management used by the Australian Fisheries Management Authority makes extensive use of harvest strategies and includes all key interest-groups in assessment of stocks and decision-making.[12] Several conditions need to be met if this kind of 'co-management' is to work; the Authority's system meets them well.[13] Naturally tensions arise, but there are clear goals and decisions are adhered to.

Numerous species in addition to prawns, Penaeus, *the target of the catch, are shown in this image. These are known as 'bycatch'; their numbers have been progressively reduced by improved gear and fishing techniques supported by research. The northern prawn fishery has recently been certified as sustainable by the Marine Stewardship Council, a certification which demanded the reduction of bycatch. Photo: CSIRO.*

Catches from two simultaneous tows of prawn nets without (left) and with (right) turtle-excluder devices. The latter have a chute on the top of the net near its mouth, allowing large, strongly-swimming animals to escape while still channelling most of the prawns to the end of the net. Bycatch of large animals like sharks and sea turtles is greatly reduced by the devices. Photo: Garry Day, AMC.



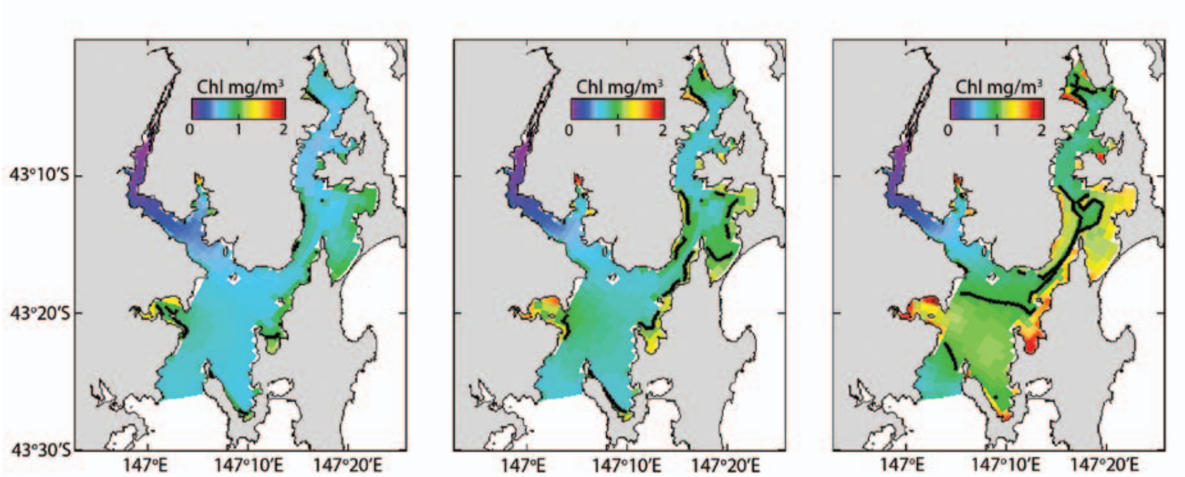
Seamount at 1338 m depth showing a sharp contrast between typical deepwater coral assemblage on the right and apparent removal of the assemblage from a single trawl passage on the left. Recovery in the cleared area is expected to be very slow. Photo: CSIRO.

Both understanding and approaches to management have progressed, and fishers and managers have now embraced the idea of ecosystem-based fisheries management, which aims to maintain ecosystem, species and genetic diversity. The move to ecosystem-based management puts us into complex decision-making territory where there may be no 'win-win' solutions and compromises have uncertain outcomes, so practice lags behind the theory (see also the discussion of 'wicked' problems in Chapter 4). Nevertheless, significant progress has been made and Australia is regarded internationally as leading in the application of ecosystem-based management.[14] One example may be the Commonwealth Marine Reserve Network, which is intended to be managed adaptively. Achieving the primary objective of providing for the protection and conservation of biodiversity and other natural or cultural values, while also providing for the sustainable use of natural resources (where there is no conflict), will require considering activities outside the reserves. The joint consideration of conservation and sustainable exploitation will help break down barriers between sectors and help create the opportunity for scientists to provide integrated advice to all managers.

Aquaculture

Aquaculture is required to fill the gap between wild-caught sources and the growing demand for healthy seafood. But the task is not simple! Aquaculture has to expand in the face of many

Atlantic salmon farm, Huon Estuary, Tasmania. Photo: CSIRO.



▲ ***Figure 9.6****: Biogeochemical model of the Huon Estuary and D'Entrecasteaux Channel, Tasmania, developed to allow proactive management of potential nutrient pollution. The figures show annual mean chlorophyll concentration in the top 13 m of the water column from the model scenario without farm inputs (left); with 2002 farm inputs (middle); and with projected future farm inputs (right).*[16]

uncertainties and most of them encompass some aspect of biodiversity. They include unwanted environmental effects such as increased nutrients, and the sustainable provision of food. Tuna are still largely fed on small fish – such as anchovies – that are caught in the wild, with potential knock-on effects for other species, such as whales and penguins, that depend on them. Scientists are at present working on two ways around this. First, if the genes for the production of omega-3 oils can be inserted from marine microalgae into crops, this would reduce dependence on marine sources. Salmon and barramundi are already largely fed on terrestrially sourced food, but this reduces the omega-3 content and also competes with other possible uses for farmland. Second, it is now possible to grow food for prawns based on marine micro-organisms feeding on waste organic matter.[15] This new way of using marine biodiversity does not use valuable farmland.

Salmon farming (Figure 9.6) is adding nutrients to the Huon Estuary and D'Entrecasteaux Channel in Tasmania, increasing phytoplankton, which has knock-on effects up the food chain. The planktonic microalga *Noctiluca scintillans* has extended its range from the north into this ecosystem, probably in response to climate change, altering both zooplankton abundance and sedimentation and making the ecosystem work differently. The authorities have limited the number of future fish farms and set up a monitoring program.

Complementary management

Australia has been grappling with the challenge of integrated management of multiple uses of marine resources for over a decade. When Australia's Oceans Policy was introduced in 1998 it was hailed internationally as the first comprehensive, ecosystem-based, multiple-use management scheme. It is now a Marine Bioregional Planning Program, within which has been established the Commonwealth Marine Reserve Network, part of the National Representative System of Marine Protected Areas. There is as yet no policy for fully integrated marine planning and management, but as a step towards it, we can envisage complementary management where scientists collaborate to ensure that individual jurisdictions understand the implications of their actions on each other.

Despite the patchy progress, where instructive solutions to biodiversity issues in the sea are adopted well we can learn from them: first, how long it takes to institute effective change; and second, some of the mechanisms that are needed to make them work properly. As with many natural resource issues, the fisheries experience teaches us that successful management requires several features:

- Strong governance and clear responsibilities
- Transparency and trust
- Avoidance of perverse incentives (i.e. unintended consequences from laws and regulations leading to undesirable results contrary to the interests of society)
- Agreed controls
- Independent monitoring
- Ongoing collaboration between science, management and all those with an interest in the system.

ISSUES OUTSIDE NATIONAL BOUNDARIES

Australia contributes strongly in the international arena to support improved management of regional marine resources beyond our borders (Box 9.4). Connectivity in the seas requires this, to achieve sustainable harvesting and to respond to regional environmental issues. The experience is valuable, because solutions to other emerging problems, such as climate change and food security, require similar international cooperation.

Box 9.4: Ups and downs in the management of the southern bluefin tuna fishery

The southern bluefin tuna, *Thunnus maccoyii*, has long been known as a traveller. It spawns near Indonesia, swims into the Indian and South Atlantic oceans and around southern Australia and New Zealand, and is fished by six or more nations.

Such highly migratory species are managed under international conventions by regional fisheries management organisations. The Commission for the Conservation of Southern Bluefin Tuna is such an organisation, established in 1993, with a scientific committee to which Australian scientists contribute.[17] But scientists depend on reliable data, which in turn rest upon transparency and trust, and there have been problems with unreported catches of tuna.

Working on sensitive issues in international bodies requires a level of diplomacy in scientists that is rarely acknowledged or taught. Only through working at the front on these contentious issues can science have impact, through understanding of both the potential and the limits of science in decision-making. It takes a long time but eventually bears fruit; in 2011, the Commission adopted a scientifically tested, adaptive rebuilding strategy for the tuna stock.[18]

The quality of the data on tuna, and its independence from the fishery, are also improving: Australian scientists are using ‘smart’ tags and techniques based on close-kin genetic matching to estimate population size. Finally, innovation in aquaculture may also help reduce pressure on the fishery.

FUTURE DEVELOPMENTS

The biggest obstacle to understanding biodiversity in the sea, and providing clear advice on managing it, is still the difficulty of describing and measuring it. Rapid technological advances are telling us more about biodiversity than we dared hope a few years ago, and we can see further developments just around the corner. We can also anticipate exciting progress in making the data available to users (see 'Smarter techniques' above). An important step would be an international version of our Integrated Marine Observing System, with sufficient capacity-building to make it truly international and focused to support decision-making. This would allow development of ecosystem-based management of oceans in the future and address the first general challenge – the need for appropriate information.

The second general challenge – the need to clarify goals for management – will not be satisfied merely via reliable data and good models, but may require arrival at societal decisions in ways that are not yet familiar. Management styles will need to be adaptive (see Chapter 4). Scientists will need to expedite technical collaboration between the different disciplines. Most importantly, our society will have to achieve effective involvement of people from many walks of life in working towards decisions. Social science and economics continue to increase in importance as a component of biodiversity science.

These matters are so complex, with so many stakeholders and inevitable controversies, that discussions become political, stressful, and confused. Science can help. It can play a 'trusted adviser' role – providing information on the range of available options and their potential consequences, for all interested parties to consider.[19] For science to play this role, open minds and a willingness to consider all options are required both in scientific institutions and in wider society.

FURTHER READING

Crist DT, Scowcroft G, Harding JMJ (2009) *World Ocean Census. A Global Survey of Marine Life*. Firefly Books, Buffalo, NY.

Hinrichsen D (2011) *The Atlas of Coasts and Ocean: Mapping Ecosystems, Threatened Resources and Marine Conservation*. Earthscan, London.

Worm B, Hilborn R, Baum JK, Branch TA, Collie JS *et al*. (2009) Rebuilding global fisheries. *Science* **325**, 578–585.

Inland waters

Carmel A. Pollino and Carol Couch

Key messages

- Australia has unusual inland water ecosystems, particularly within arid and semi-arid parts of the continent, which are characterised by boom-and-bust extremes in water availability.
- Inland water ecosystems and groundwater-dependent ecosystems are vulnerable to change in water availability, caused by extraction of water for human uses.
- Solutions to declining freshwater biodiversity include a more sustainable balance between water allocated to the environment versus other uses, habitat restoration in rivers and streams, and management strategies to control invasive species.
- Australia is a world leader in policies for water resource management, including environmental flows.

AUSTRALIA'S INLAND WATERS

In one of the world's most arid continents, Australia's inland waters support a rich diversity of life. Biodiversity is enhanced by the gradual change in the climate from the northern tropics, through a dry interior, to temperate zones in the south. Australia's inland waters are further characterised by variability, which has shaped ecosystems over millennia and, more recently, driven human development to manage water resources. Significant numbers of plants and animals are dependent on inland water ecosystems, either fully or periodically, during at least part of their life-cycles. These species include fishes that live in rivers or lakes, waterbirds that forage and breed in wetlands, and floodplain eucalyptus trees that require periodic inundation by floodwaters.

Australia receives an overall average of 417 mm of rainfall per year; however, the wide variation in rainfall across regions governs the nature and character of inland waters and their biodiversity.[1] Inland water ecosystems include lakes, rivers, floodplains and wetlands, as well as waterbodies in rock cavities deep below the Earth's surface. Some inland waters, especially the waterbodies in rock cavities, depend on groundwater (i.e. water held beneath the Earth's surface in soil-pore spaces and in the fractures of rock formations) to maintain their ecosystems. Inland waters may be fresh or saline. Some water bodies have natural salt concentrations with salinities greater than that of sea water (described as 'hyper-saline'). For example, Victoria's largest natural lake, Lake Corangamite, is naturally hyper-saline.

This chapter looks at this wide range of ecosystems and the management challenges that they present.

Australia's inland water ecosystems, such as this billabong in Kakadu National Park, Northern Territory, support a rich array of biodiversity. Photo: John Coppi, CSIRO.

Dynamics of change: boom and bust

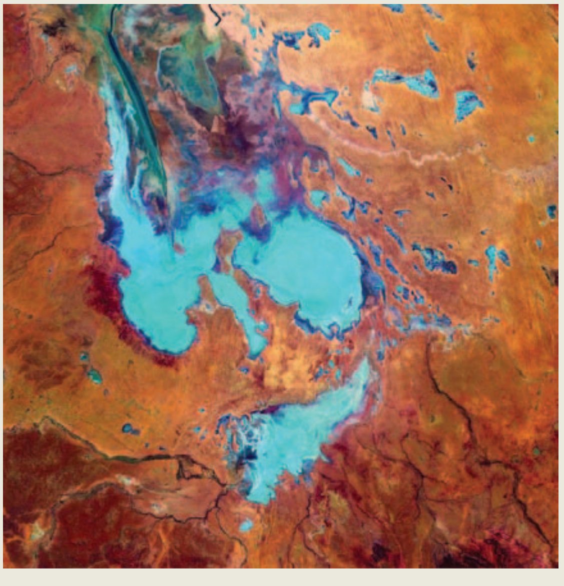
As we have seen earlier (Chapter 2), Australia's climate is inherently variable. Hence, inland rivers are freshwater systems of low water-yield but of high variability. For example, in dry periods the Paroo River of New South Wales contracts to a series of waterholes and lakes, but large floods can inundate approximately 800 000 ha. In boom periods, thousands of small creeks feed large wetlands or lakes and vast floodplains fill. The watercourses formed during these periods eventually dry out into meandering braided channels, billabongs and waterholes, exchanging nutrients through the landscape and creating a series of habitats for plants and animals while doing so. The extent of this variability is extreme compared to most of the world's river systems (Box 10.1).

Our aquatic ecosystems have adapted to the dynamics of 'boom and bust', of extreme dries and wets. Most of the habitat that the floods create is fleeting. Some species use these areas and the resources that they offer opportunistically, whereas others rely on the persistence of freshwater refuges for their entire life-cycle. Many fishes use the floodplain as nursery areas for their young; species of frogs that have persisted in burrows during the dry engage in a frenzy of reproduction; and waterbirds migrate long distances to collect in colonies. The inevitable busts follow, extending much longer than the flush and reducing the rivers to disconnected waterholes.

Box 10.1: Kati Thanda–Lake Eyre – epitome of boom and bust

Kati Thanda–Lake Eyre is the fifth-largest terminal lake in the world. It occurs in a region where evaporation far outweighs precipitation. and covers 9690 km^2 of mainly dry salt-pan until the rivers and creeks flood its surface. The boom and bust nature of the region drives the ecology of Kati Thanda–Lake Eyre. Few animals or plants tolerate the extreme salinity of Kati Thanda–Lake Eyre but, given enough fresh water, an explosion of life is triggered. Warm water and the growth of phytoplankton provide ideal conditions for millions of invertebrates to proliferate, and soon the fish and waterbirds arrive.

In 2009 Kati Thanda–Lake Eyre flooded. The lake system provides an end point for channel flows, food web processes and primary production, supporting fish populations and, finally, more than a million waterbirds. Human use of some resources is also ephemeral, with graziers using the surrounding areas for cattle in the boom times, moving them out during the downturns. By 2012 the lake dried to form a series of creeks and pools.



Satellite image of Kati Thanda–Lake Eyre filling. Photo: Goddard Space Flight Center's Landsat Team and the Australian ground receiving station teams.[2]

Floodplains: productive systems

Inland river ecosystems are much more than just the main river channel. They are made up of extensive floodplains, formed when the river breaks its banks and flows over low-lying land, including channels, lakes, billabongs, wetlands and waterholes. Floodplains can comprise over 90% of the riverine ecosystem and are fundamental to its functioning. The flow in an inland river creates a diversity of habitats, first as it expands and then as it contracts and breaks up into fragments of differing sizes and durations.

Carbon is supplied into floodplains during wet phases, and because it provides an energy source it supports the biodiversity of soil and, in turn, the working of the entire ecosystem. Flooding must occur sufficiently often to replenish the soil carbon in floodplains, and subsequently to carry it along rivers to other places. Dams on inland rivers have interrupted this cycle, however, as they 'capture' floods and restrict inundation. When the irregular but reliable flood regime is lost, many floodplain plants are gradually replaced by more dry-tolerant species. As a result, the floodplain shrinks, biodiversity declines and floodplain productivity is reduced. These impacts can have surprisingly widespread ripple effects, such as those felt by woodland birds (Box 10.2).

Box 10.2: Woodland birds and their sensitivity to altered flows

Flooding affects woodland birds through primary productivity, habitat quality, or open water for drinking.[3] Declines among woodland birds are due to habitat loss, fragmentation and degradation, and they are further influenced by changing flood regimes and subsequent loss of floodplain productivity. Richness, diversity, abundance, density and breeding numbers of woodland birds are significantly greater in floodplains and riparian zones compared to 'dry' non-floodplain and agricultural environments.

For example, a study in the Murrumbidgee Catchment of New South Wales found that floodplains support greater abundances of birds. Regions irrigated at low to medium intensity may also provide significant habitats for woodland birds, particularly during drought periods. These benefits are probably mediated by positive vegetation responses to greater water availability from higher groundwater tables. However, in areas of high-intensity irrigation there were negative effects on woodland birds, including an increase in the abundance of feral species such as starlings, *Sturnus vulgaris*, and competitive natives such as noisy miners, *Manorina melanocephala*.

Apostlebirds, Struthidea cinerea*, at Yanga National Park, New South Wales. Photo: Heather McGinness, CSIRO.*

Groundwater: the hidden resource

Groundwater is often overlooked despite being important in the water cycle. Groundwater-dependent ecosystems are geographically small, yet they are an important part of Australian biodiversity. Groundwater-dependent ecosystems are frequently connected to surface waters. In perennial rivers, such as the Daly and Roper rivers of the Northern Territory, permanent base-flows are maintained by groundwater inputs during the dry season. Base-flows allow fishes to persist through the dry season, and are important areas of production for aquatic invertebrate animals.[4]

Groundwater-dependent ecosystems may also be isolated from surface waters, occurring instead as subterranean water-filled cavities in limestone or fractured rock. Here they are often inhabited by mysterious animals found in no other ecosystem, known as stygofauna (see Chapter 2).[5]

Although groundwater-dependent ecosystems may be out of sight they contribute to economic, cultural and scientific values. All Australian governments now require water plans to recognise the ecological value of water, including groundwater.[6] Groundwater may be heavily relied upon for water extraction but the impacts of this may not be manifested until too late to undo any harm. Characterising these impacts represents a gap in knowledge, one important contribution to which is the *Atlas of Groundwater Dependent Ecosystems* released by the Bureau of Meteorology.[7]

Australia's endemic biodiversity of inland waters

A notable characteristic of inland water biodiversity is the high proportion of endemic species – those species restricted in their geographic ranges such that they are only found in certain catchments. Endemic species are often the focus of conservation because their loss in one region cannot be replaced from populations living elsewhere. Endemism is characteristic of many groups, including crayfish, mussels, stygofauna and frogs. For example, 94% of our frog species are found only in certain inland ecosystems – the highest rate of endemism among Australia's vertebrate species.[8]

The New Holland water-holding frog, Cyclorana novaehollandiae. *Photo: Danial Stratford, CSIRO.*

The number of native Australian inland fishes is relatively small (about 280) in comparison to other continents (South America 2000, North America 600, and Africa 1400).[9] However, approximately 70% of Australian inland fish species are endemic; further, they show unusual adaptations to highly varying environmental conditions. The highest endemism is found among the central, southern and western basins that are characterised by aridity and long-term isolation.

WATER RESOURCE DEVELOPMENT: ADAPTING TO A VARIABLE ENVIRONMENT

Aridity and variability in rainfall had a profound influence on the last two centuries of Australian history, resulting in efforts to secure water supplies by manipulating flows. Water remains today among the natural resources most highly sought after by humans. Irrigated agriculture is reliant on both surface water and groundwater resources, using storages, canals, pipes and channels to offset climatic unpredictability. Consequently, throughout Australia there are now multitudes of water-control devices including locks, floodplain levee banks, and dams. Many lakes, rivers, wetlands, and groundwater ecosystems have been altered as a result of water development. Many rivers are now 'working rivers', in which natural flows have been reduced and which have been turned into delivery systems for human use of water (Box 10.3).

On average, across the continent only 6% of water resources are consumed each year.[1] However, the highly uneven distribution of these resources and their use by people results in some inland waters being fully or over-allocated, while others remain undeveloped. Most irrigated agriculture occurs in the south in areas where run-off happens naturally to be lower (Figure 10.1). The highest use of surface water occurs in smaller water supply catchments around cities. In the Murray–Darling Basin, on average, 48% of surface water is extracted each year, whereas consumptive water use in coastal basins draining northern Australia is frequently less than 5%.

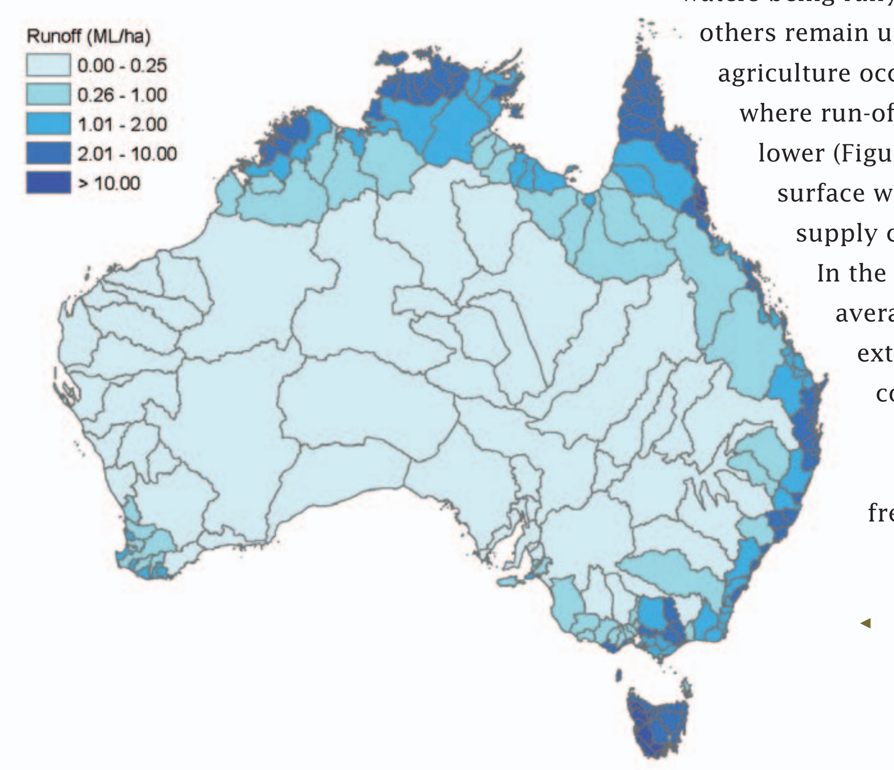


Figure 10.1: *Annual average distribution of run-off from each drainage division in 2004–05, with lines indicating catchment boundaries.*[1]

Box 10.3: The Murray–Darling Basin – a history of development

Dams were built on the Goulburn, Murray and Murrumbidgee rivers early in the 20th century to meet the needs of irrigation. Dam-building then moved to more northern and inland rivers, and finally into upper catchments after the 1950s (the last in 1995). Dams in the Murray–Darling Basin have the capacity to hold around 25 000 gigalitres, which is about one year's run-off, and consequently flow regimes are highly modified. Today, irrigation in the Basin contributes to 60% of Australia's agricultural production.

The storages are designed to smooth the year-to-year variability of flows in the system and provide more consistent delivery to water users. Combined with water extractions, smoothing has reduced the total volume of flows, thereby reducing the seasonality, frequency and duration of wet and dry cycles. These changes have profoundly affected the ecology of the Basin, including loss or alteration of wetlands; decline in extent and condition of vegetation on floodplains; decline in the abundance and diversity of native fishes, invertebrates and waterbirds; reduction in water quality; and invasions of non-native species.

In response, policies aimed at re-balancing over-allocation of water and in rehabilitating ecosystems have led to significant investments in the purchase of land and water entitlements and in infrastructure to deliver environmental water. The *Water Act 2007* states that the Murray–Darling Basin Plan must 'promote sustainable use of the Basin water resources to protect and restore the ecosystems, natural habitats and species that are reliant on the Basin water resources and to conserve biodiversity'. One of the challenges in water resource planning has been the paucity of scientific knowledge to establish ecological requirements for and to predict consequences of environmental flows.[10]

Cataract Dam and Reservoir, New South Wales. Photo: Gregory Heath, CSIRO.

Unlike the Murray–Darling Basin, water resources in northern Australia are relatively lightly exploited. Northern Australia contains more than 50 major rivers and many hundreds of smaller streams. Freshwater ecosystems are diverse, supporting at least 170 fish species, 150 waterbirds, 30 aquatic to semi-aquatic reptiles, over 60 amphibians and over 100 macro-invertebrate families.

Planning for water resource developments is underway, although many gaps remain in scientific knowledge.[11]

Aboriginal ecological knowledge

Use of Australia's inland water extends back tens of thousands of years. Aboriginal lives often centred around waterholes or wetlands, which provided resources of food and shelter. A rare example of Aboriginal use of inland water resources remaining in irrigated catchments is the Brewarrina Aboriginal fish traps (*Baiame's ngunnhu*), a complex arrangement of stone traps, channels and rock walls covering 400 m of the river bed. The fish traps are believed to be as much as 40 000 years old, and they demonstrate an intimate knowledge of the behaviour of fish. Inquiry into Aboriginal water values and traditional knowledge of the ecosystem is increasingly important in managing water.[12]

A section of the Brewarrina Aboriginal fish traps. Photo: Bradley Moggridge, CSIRO.

Challenges to biodiversity of water resource development

The most important variable to explain challenges to inland water biodiversity is water movement – hydrology.[13]

Changes to water flows

Many of Australia's rivers are affected by activities that disrupt hydrologic regimes and the ecological processes stemming from natural wetting and drying cycles. Changes in flow that exceed the environmental bounds – and consequently the reproductive requirements of many species – ultimately lead to changes in biodiversity. River floodplains are particularly vulnerable to change, especially in arid regions.[14]

Habitat loss, degradation and fragmentation

The timing, amount and quality of water are the principal factors influencing persistence of habitats essential to water-dependent species. Habitat fragmentation occurs when weirs, dams, pipes, regulators and irrigation diversions prevent dispersal or access to breeding habitats. For example, an estimated 10 000 dams and weirs are located on main channels in the Murray–Darling Basin, hindering the passage of fish to feeding, spawning, or sheltering habitats and diminishing their ability to recolonise after droughts or high flows.

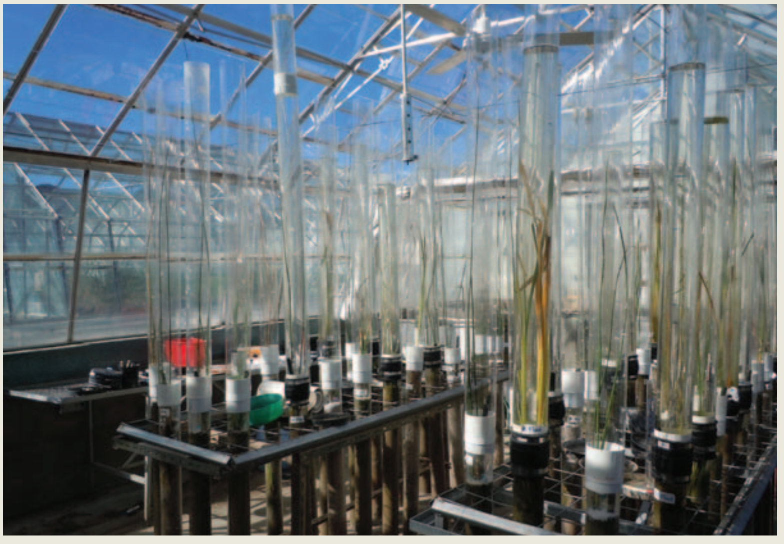
Invasive species

The best-documented example of non-native invasive species in inland waters is the fishes of the Murray–Darling Basin. Populations of the 46 species of native fish are now at about 10% of the numbers present before European settlement.[15] Twelve non-native invasive fishes now inhabit the Basin, with European carp, *Cyprinus carpio*, and red-fin perch, *Perca fluviatilis*, predominating. Carp alter habitats and productivity by destroying aquatic plants, increasing water turbidity and disrupting the feeding of native species, while red-fin perch eat the smaller native fish. Other invasive species are native, where one species dominates another due to changes in habitat (Box 10.4).

Box 10.4: Invasive species, changes in flow and habitat loss

The Barmah–Millewa Forest is a floodplain located on the Murray River. A dam has substantially altered the natural flood regime, resulting in changes to the flora and fauna of the forest. One major change is the loss of semi-aquatic grasslands dominated by moira grass, *Pseudoraphis spinescens*, a significant habitat for colonially-nesting waterbirds. Moira grass has been replaced by the native invasive giant rush, *Juncus ingens*, which forms dense monocultures. Even after recent prolonged floods, the invasive rush still dominates, suggesting a possible permanent transition in vegetation.

The strategy for management is to use environmental flows to restore the degraded floodplains. However, the flood requirements of these two key species are little known, so research is being undertaken to determine them and to explore whether the transition to giant rush is permanent.



Determining water requirements of giant rush using glasshouse experiments. Photo: Lyndsey Vivien, CSIRO.

Measuring water properties during a blue-green algal bloom in Chaffey Reservoir, New South Wales. Photo: Brad Sherman, CSIRO.

Climate change

Southern Australia is likely to experience more frequent and intense droughts in future, whereas northern Australia is predicted not to be so affected. The rate and magnitude of climate change are likely to outpace adaptation by inland water species and ecosystems, but there is comparatively little known about the consequences for biodiversity.[16]

Use of natural resources

Inland waters are embedded within ecosystems subject to varying uses and, as a result, management can profoundly influence the quantity and quality of their waters. Erosion of soils in agricultural catchments can cause sediment run-off into streams, changing turbidity and habitat for aquatic organisms (see Chapter 7). Nutrient run-off can lead to blooms of nuisance algae, causing fish kills and rendering water unsuitable for human use. These are also affecting the Great Barrier Reef (Chapter 3). Land clearing and infilling of wetlands are all past legacies with lasting impacts on the biodiversity of inland waters.

MANAGEMENT OF INLAND WATER BIODIVERSITY

Three advances in water management are notable for their successes and future potential.

Environmental water management in over-allocated catchments

Competing demands for water make it necessary to provide a share of water for the environment in order to halt decline. The National Water Initiative is the blueprint for water reform in Australia. It was signed by the Council of Australian Governments in 2004, and confirmed in legislation by the *Water Act 2007*. Environmental water holdings are now in place for many water-stressed catchments, and environmental flows are used to mimic components of natural variability in magnitude, frequency, seasonality, duration and sequencing of flows. Many environmental objectives can thereby be met:

- Providing breeding opportunities for water-dependent plants and animals
- Creating or prolonging connection of rivers, floodplains and wetlands to promote migration of flora and fauna, ecosystem diversity and ecological functions
- Maintaining refuges during extreme drought.

Adaptive management is essential for complex and inherently variable ecosystems, where change and outcomes are difficult to predict. Field-studies of environmental watering are necessary for management actions to be adjusted over time, via testing against the best available knowledge through sound scientific monitoring, and then iterative review and refinement. The Paika Lake example demonstrates adaptive management in practice (Box 10.5).

Box 10.5: Adaptive management of environmental flows

Paika Lake is located in the Murrumbidgee Catchment of New South Wales. Paika Lake and surrounding local wetlands had been isolated from flooding for over 100 years, being disconnected from the Lowbidgee floodplain by levee banks and roads. Restoration of water to Paika Lake and surrounding wetlands began in 2011. Opening up the historical flows has resulted in the arrival of 20 000–40 000 waterbirds of over 35 species, including three threatened species, the blue-billed duck, *Oxyura australis*, freckled duck, *Stictonetta naevosa*, and Australian painted snipe, *Rostratula australis*. Environmental water has also benefited river red-gum forest, and adjacent to the wetlands seedling regeneration is abundant. The wetland responses are now being used to inform continuing land and water management, demonstrating adaptive management in action.[17]

Automatic time-lapse images showing the same view two weeks apart at Paika Lake, New South Wales. Time-lapsed images enable monitoring of changes in inundation and resultant responses by vegetation and birds. Photos: Heather McGinness, CSIRO.

Adaptive management requires monitoring to understand the outcomes of decisions, to improve the state of knowledge and to inform the next step in decision-making (see Chapter 4). Monitoring can be expensive and limited in scope. Advanced genetic techniques, termed 'metagenomics', can help us explore the diversity of organisms in complex environments and improve understanding of the effects of management. Bacteria and animals living in the sediment leave behind traces of their DNA and metagenomics can be used to read the sequences of the DNA to identify thousands of organisms. Bacteria are the worker bees of the soil: they cycle carbon and nutrients, and so any disruption to these processes can affect the functioning of ecosystems. A study of soils in a river red-gum forest of the Murrumbidgee River found a rich diversity of animals and plants, with over 2500 different organisms identified.[18] Many of them had been subjected to 10 years of drought, and at some sites this had been followed by inundation for a year. Survival through the extremes of drought and flooding demonstrates resilience of these largely invisible components of biodiversity.

Habitat restoration for floodplains and wetlands

Some land management practices in agriculture have left a legacy of erosion, altered water quality, changes to riparian plant communities, and loss of native aquatic plants and animals. Now, multi-million dollar investments are being made to improve aquatic ecosystems and to ensure their sustainable use. One of the most significant environmental problems in irrigated catchments is salinisation. Salt is naturally present in many landscapes, and dissolved salts are brought to the surface by rising groundwater levels that result from the removal of the native vegetation that originally kept the water table low, and also as a consequence of some farming practices. Management strategies include the use of salt-tolerant plants; planting of deep-rooted crops and pastures; revegetating with native plants; engineering to divert saline waters (Box 10.6); and prevention of further clearing in vulnerable areas such as groundwater recharge zones.

Fenceposts on an expanse of salinised land in the Western Australian wheatbelt, near Meckering. Photo: Willem van Aken, CSIRO.

Box 10.6: Managing salinised floodplains

The Bookpurnong floodplain of about 1800 ha lies next to the River Murray in South Australia. Irrigation has led to greater salinity at the soil surface and in the aquifer, and to manage this problem a salt interception scheme was built in 2007 to protect and rehabilitate the river and floodplain. Field trials were conducted to explore the effectiveness of different options for managing the salinised floodplain. The study demonstrated that the benefits of the interception scheme were localised, and that a long-term systems-based approach to management is needed.[19]

Management of vegetation on the floodplain needs to consider both surface waters and groundwater, such that inundation can replenish and freshen soil and the saline aquifer. Single inundations result only in a temporary improvement in vegetation condition; consecutive inundation is needed for sustained groundwater freshening and for continual removal of salt from the root zone. Groundwater management can improve tree health by increasing recharge to maintain the low-salinity water that floodplain trees rely on between floods.

Dead trees on Bookpurnong floodplain. Photo: Arthur Mostead, Murray-Darling Basin Authority.

Management of riparian zones is an effective way of restoring biodiversity in the broader landscape. Through such management, sediment and nutrient run-off can be reduced, channel erosion prevented, shade provided to a stream for temperature control, and wildlife corridors re-established in fragmented landscapes. Riparian zones are highly productive, and act as refuges during droughts and as protection from fires. Restoration of riparian zones is becoming a collective effort involving farmers, landholders, community groups, regional natural resource management organisations, government agencies and industry bodies.[20]

Managing invasive species

Invasive species – mostly non-native – compete for or destroy habitat and food resources. In Australia, there are at least 65 non-native aquatic plants. Tropical rivers are vulnerable to invasions of mimosa, *Mimosa pigra*; rubber vine, *Cryptostegia grandiflora*; and *Parkinsonia aculeata*. River systems have been affected by weeds, including water hyacinth, *Eichhornia crassipes*; lippia, *Phyla canescens*; willows, *Salix* species (Box 10.7); and alligator weed, *Alternanthera philoxeroides*.[21] Hydrologically disturbed wetlands are more likely to have fewer species of native plants and higher incidences of invaders.[22]

There are at least 20 species of introduced fishes in Australia inland waterways.[20] In a recent audit of river health in the Murray–Darling Basin, the European carp, *Cyprinus carpio*, made up 60% of the total biomass.[23] Other vertebrate pests in Australian river systems include the cane toad, *Rhinella marina*; feral pigs, *Sus scrofa*; water buffalo, *Bubalus bubalis*; and banteng cattle, *Bos javanicus*.

Although many invasive species are introduced, native species such as the giant rush (Box 10.4) can be also opportunistic invaders. Another example is cumbungi, *Typha orientalis*, which is an invasive in Western Australia, but is native to eastern Australia.

Box 10.7: Weeds and water savings

Willows are non-native invasive trees of many waterways and wetlands in south-eastern Australia, including Tasmania. They form large, dense, shallow root masses that invade riparian ecosystems, out-competing native vegetation and occupying stream beds. Willows slow stream flow, increase flooding, and consume large volumes of water. They propagate vegetatively, twigs being able to grow into new trees at new sites. Programs of removal have been undertaken over decades with varying success. Experience shows that without revegetation of a recently cleared area and ongoing rehabilitation, willows may re-invade.

Water use by willows is large: studies show that more than five and a half megalitres of water could be saved annually for every hectare of willow canopy removed (for trees in-stream with permanent water). The evaporative loss of 1 ha of willows is enough for about 17 households each year. A comparative study on the same watercourse showed that replacement of willows by native vegetation could lead to maintenance of the annual water savings, with water use by eucalypts being approximately one-third that of the willows.

The public company Water for Rivers (an initiative of the Commonwealth, New South Wales and Victorian governments) recently removed 170 ha of willows in north-eastern Victoria and 50 ha in the Yanco Creek, Murrumbidgee, Yass and Murray rivers. This removal has returned 1200 megalitres of water a year to these river systems. At a market price for high-security water of $2000 per megalitre, the five and a half megalitres per hectare per year used by willows is worth about $2.4 million.[24]

Riparian area invaded by willows. Photo: Tanya Doody, CSIRO.

NEXT STEPS

Australia is one of few countries in the world with a strong policy framework for the effective management of river systems. There is growing community understanding of the link between water use and declining ecological health of inland rivers and their floodplains. Extensive areas of suitable land and ample water resources will remain under high demand and have been identified for expanding irrigated agriculture and mining activities, particularly in northern Australia.

Experience teaches us that water reform in over-allocated catchments is contentious, costly, and dependent for success on informed debate. Science helps here by underpinning rehabilitation and restoration, drawing upon knowledge of climate, flow regimes, genetics, movement patterns, water requirements and ecological processes. Despite significant investments, there remains limited information on inland water ecosystems and even less regarding groundwater-dependent ecosystems.[25] Research is underway to improve knowledge of drivers of ecosystem change, in monitoring technologies, and in development of predictive tools to assist decision-makers.

Whether considering a freshwater system already altered or one that is planned for development, decision-makers should have access to information and knowledge of water availability and biodiversity. Enhancing and promoting individual and community participation in decision-making for water resource management is among the most effective ways of achieving conservation, rehabilitation and sustainable management of inland waters.

FURTHER READING

National Water Commission (2012) *Assessing Water Stress in Australian Catchments and Aquifers*. National Water Commission, Canberra.

Prosser IP (Ed.) (2011) *Water: Science and Solutions for Australia*. CSIRO Publishing, Melbourne. <http://www.csiro.au/en/Outcomes/Water/Water-Book.aspx>.

State of the Environment Committee (2011) *Australia State of the Environment 2011: Independent Report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities*. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra. <http://www.environment.gov.au/topics/science-and-research/state-environment-reporting/soe-2011>.

Mining and biodiversity

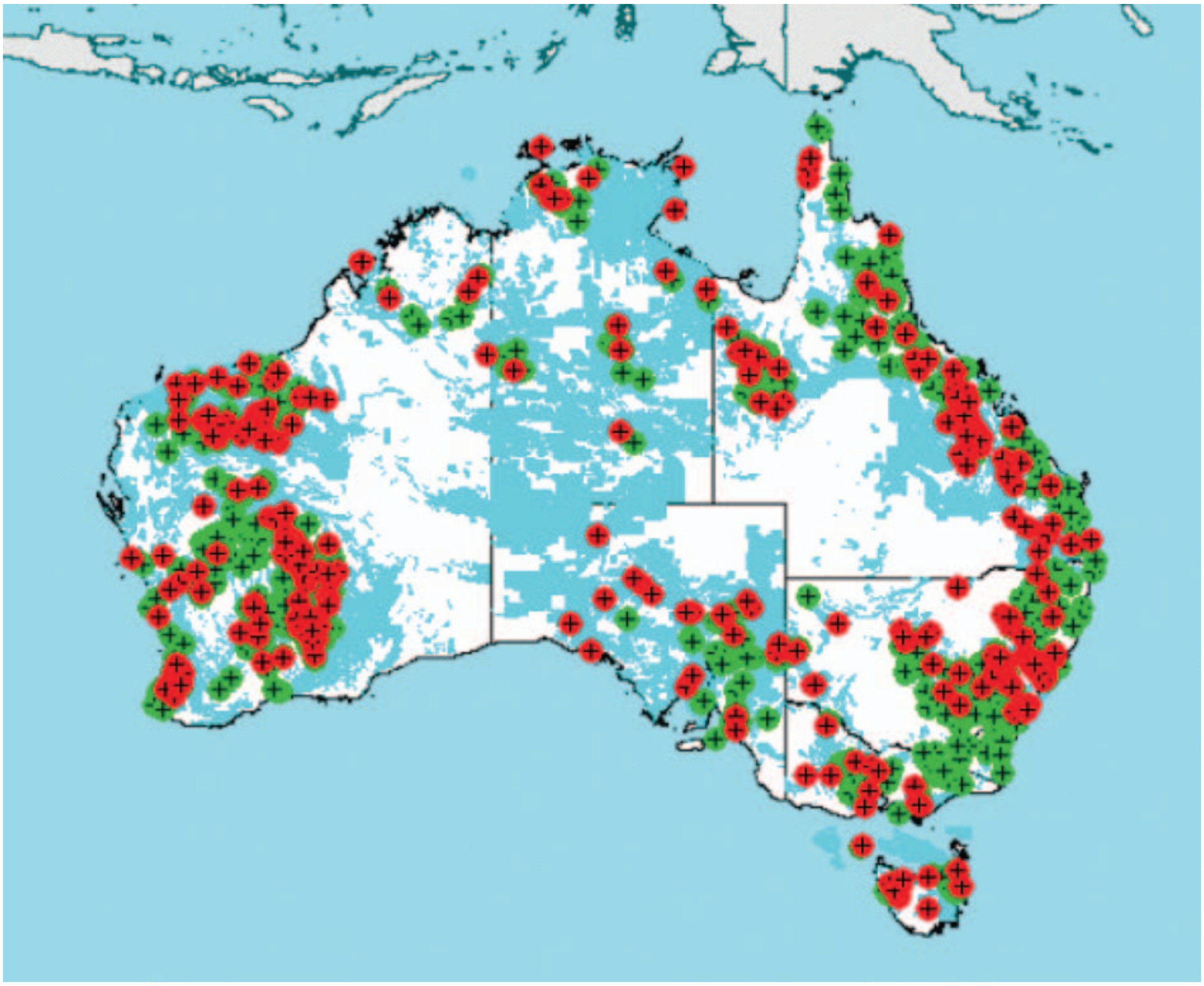
Alan Andersen, Garry Cook and Nicholas Bax

Key messages

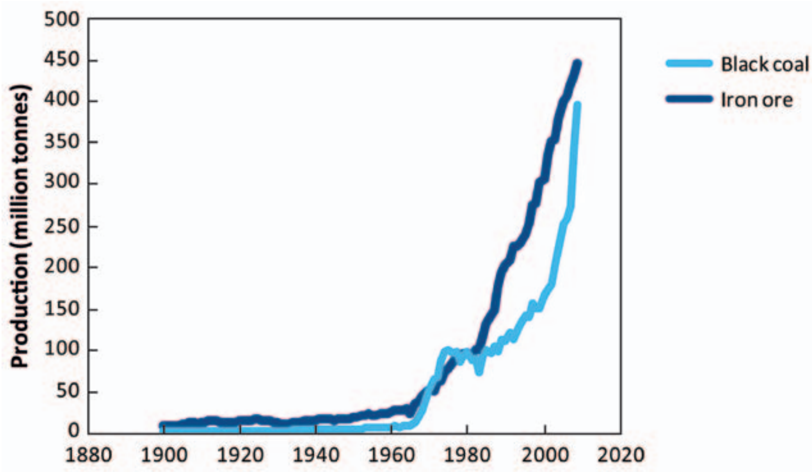
- Mining occurs throughout most regions of Australia, but its direct impacts on biodiversity are relatively limited compared with other major land uses because the areas affected are generally small.
- The greatest potential for biodiversity impacts occurs through cumulative effects of multiple projects in prospective regions, including indirect impacts from regional development; these are best managed by strategic assessments that consider whole-of-region development in the long term.
- In the past, rehabilitation projects following mining simply aimed to establish vegetation cover. Now, projects increasingly seek to develop self-sustaining ecosystems that interact sustainably with the surrounding landscape.
- Unavoidable impacts on biodiversity can be partially compensated for (or 'offset') through activities that provide conservation benefits elsewhere. Given the wealth created, there are opportunities for mining to leave a positive legacy for biodiversity conservation in the broader region.

MINING AND ITS BIODIVERSITY FOOTPRINT

Mineral prospecting and exploration are allowed throughout most of Australia (Figure 11.1), and so mining has the potential for extensive impacts on biodiversity. Many people worry about the environmental impacts of mining, but society has a growing need for its products and it is a valuable industry to Australia. Australia is a globally significant supplier of minerals and energy, holding a substantial proportion of the world's known reserves of many important minerals. Mining is vital to the Australian economy, delivering more than half of the total value of the nation's exports. Mining exports have increased rapidly over recent decades on the back of unprecedented demand from China and other developing economies, with annual production of black coal and iron ore increasing exponentially (Figure 11.2).[1]



▲ ***Figure 11.1***: *Operating (red) and historic (green) mines, and mineral tenements in which mining, exploration and prospecting is allowed (blue). Source: Copyright Commonwealth of Australia – Geoscience Australia, 2010.*



▸ ***Figure 11.2**: Australian black coal and iron ore production over the past 130 years.*[1]

Nevertheless, individual mine sites are typically small, and collectively they cover less than 1% of the Australian land area (Table 11.1).[2,3] As a result, the direct impacts of mining on biodiversity are limited compared with other major land uses.

The localised effects of mining can be important, however, and there are many examples of serious environmental impacts from old mines that operated under lax environmental regulation. In particular, the planned release or accidental leakage of contaminated water can have a major impact on local wetlands and waterways. For example, 100 years of release of wastes from the Mt Lyell Mine has had devastating impacts on the ecology of the King and Queen Rivers in Tasmania.[4] Localised impacts can have broader significance, such as when the mining of rare but particularly prospective geological formations competes with the conservation of species or ecosystems that are endemic to that area. Mining can also have significant indirect impacts, such as through extraction of water from aquifers or the Great Artesian Basin, or accidental oil spills from ships transporting minerals for export. Volumes of oil spills are predicted to increase in Australian waters by nearly a third between 2010 and 2020, due to a dramatic increase in sea traffic.[5]

Table 11.1: Land use in Australia in 2006 as a proportion of the total area of land.[3]

Land use	Percentage of total land area
Agriculture	62
Grazing natural vegetation (rangelands)	56
Dryland grazing (improved pastures)	2.5
Cropping	2.8
Horticulture	< 1
Irrigation	< 1
Minimal use	15
Traditional Indigenous uses	12
Biodiversity conservation	6
Forestry	2
Water	1.7
Managed resource protection	1.4
Urban uses	< 1
Mining	< 1
Total	**100**

The greatest potential for negative impacts on biodiversity is not from individual mines, therefore, but from the cumulative impacts of extensive development in highly prospective regions, or where diffuse exploration and development take place over large regions. Iron-ore mining in Western Australia's Pilbara and coal mining in central Queensland are examples of the former, and examples of the latter are coal seam gas development in eastern Australia and exploration for gas, oil and minerals across outback Australia. In these situations mining can dominate regional development, and potentially affect biodiversity regionally through a combination of the scale of exploration activity, the mine sites themselves and, importantly, the roads, towns, pipelines, water supplies and ports required to service them.

At a regional scale, biodiversity is likely to be affected more by infrastructure development relating to processing and transport than by mines themselves. Photo: Woodside.

This chapter focuses on three issues of particular importance for managing the impacts of mining on biodiversity:

1. Cumulative impacts in highly prospective regions, which are best managed by planning that addresses whole-of-region development over the longer term, based on a comprehensive assessment of regional biodiversity assets.
2. Mine site rehabilitation, which is increasingly aiming beyond simple establishment of vegetation cover towards re-creation of biodiverse ecosystems that interact sustainably with the surrounding landscape.
3. Biodiversity offsets, which can help compensate for unavoidable on-site losses of biodiversity by activities that provide conservation benefits elsewhere in the region.

REGIONAL ASSESSMENTS

Regional assessments can limit the impacts of large-scale development by identifying the biodiversity assets of a region and establishing a planning framework by which these assets can be protected. Such assessments can also be beneficial to the industry itself by providing clear 'goal posts' for development, reducing duplication with impact assessment, and streamlining administrative processes. The Australian Government has a formal process for strategic regional assessments under the *Environment Protection and Biodiversity Conservation Act 1999*.[6] The first priority is to avoid any impacts on nationally significant biodiversity assets. If such assets are threatened, then appropriate mitigation measures are required, and if significant biodiversity impacts are unavoidable, then these need to be compensated for by appropriate offsets. There is a requirement for ongoing adaptive management to ensure that regional biodiversity objectives are ultimately achieved.

A regional strategic assessment process has recently been implemented for the Great Barrier Reef (see Chapter 5 for more detail). Most of the threats to the Great Barrier Reef have their origins outside it, and include catchment run-off, coastal development and climate change.[7] No mining, oil or gas development is allowed in the Great Barrier Reef Marine Park. However, the booming mining industry in central Queensland means that coastal development pressures, including ports, are increasing rapidly, with shipping traffic to Queensland ports predicted to increase four-fold by 2020. Managing such development pressures is a challenge, particularly while trying to protect a globally significant natural wonder that is becoming more vulnerable due to climate change. These pressures are threatening the World Heritage status of the Great Barrier Reef Marine Park, with UNESCO concluding that development of new ports or other major infrastructure would have a significantly negative, and largely irreversible, impact on its biodiversity.[8]

Although mining, oil and gas developments are not allowed inside the Great Barrier Reef Marine Park, there is international concern about the negative impacts that increased coastal development, resulting from the central Queensland mining boom, could have on the Reef's biodiversity values. Photo: Marie Davies.

Projects under the aforementioned strategic assessment are defining the biodiversity values of the Reef, examining cumulative impacts, and designing an integrated monitoring program. There are existing monitoring programs being undertaken by government, industry and non-government organisations, but these could be better integrated. The new regional assessment will provide this integration, identify major information gaps, and form the basis of strategic adaptive management (Box 11.1).

Box 11.1: Marine indicators

A cornerstone of adaptive management is the monitoring of indicators that signal management success. Marine indicators are well established for single-species fisheries, but are less well developed for the broader and more complex issues of biodiversity and ecosystem health. There is often, therefore, a gap between high-level management objectives as articulated in marine bioregional plans and the capacity to measure them. The linking of management needs to monitoring requires close collaboration to specify environmental objectives that are not only scientifically measurable but also meaningful to managers.

An Australian breakthrough came when the Commonwealth identified the most significant areas for marine productivity or diversity as 'key ecological features', including seamounts, canyons and areas of upwelling or regular current eddies. CSIRO scientists then worked with regional experts to develop conceptual models for 31 key ecological features around the country. The use of simple, qualitative models to link pressures (such as climate change, fishing and mining) to these features has led to reliable indicators of ecological change that will support future State of the Environment reporting. Such simple models that capture local understanding and link operational management to monitoring are now being applied to the Great Barrier Reef World Heritage Area, as part of the assessment of cumulative impacts of rapid coastal development associated with land-based mining.

MINE SITE REHABILITATION

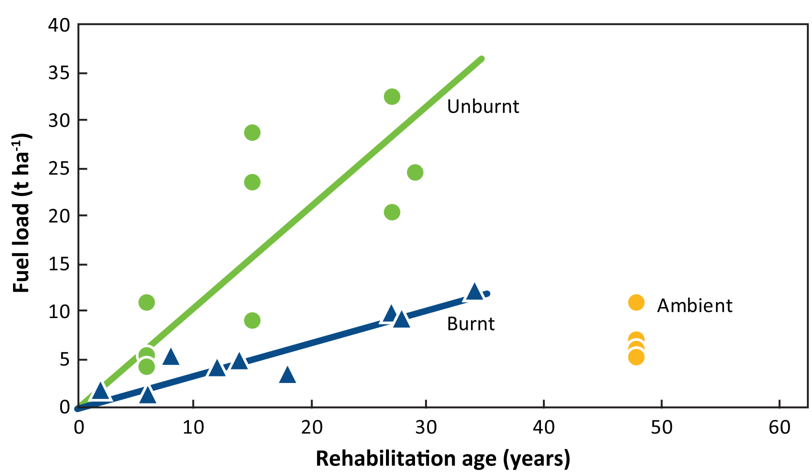
Mine site rehabilitation has historically focused on site stabilisation and the establishment of vegetation cover, but this is often now just the start of a rehabilitation process that is increasingly aimed at ecosystem restoration. Successful ecosystem restoration requires the re-establishment of animal as well as plant communities, and also the effective functioning of ecological processes such as nutrient cycling. Restored ecosystems also need to be resilient to natural disturbance, especially fire, and to invasion by weeds. In this way, the rehabilitated mine site becomes sustainably integrated with the surrounding landscape.

Fire management and ecosystem restoration

Fires are the major agent of natural ecological disturbance throughout much of Australia. Average intervals between burns range from 1 to 2 years in tropical savannas to many decades in the tall forests of temperate Australia. In highly fire-prone regions, the capacity to recover after fire ('fire resilience') is a key attribute of ecosystems, and is taken into account in effective mine site rehabilitation. There has been a major research effort into the role of fire in ecosystem restoration in bauxite mines of south-western Australia.[9] There, rehabilitated landscapes aged 12–15 years are resilient to fire, with low- to moderate-intensity spring-time burns being recommended as best practice in fire management.

For much of Australia, however, the responses of plant and animals to fire are not so well known and therefore difficult to incorporate into rehabilitation plans.[10] Even in northern Australian savannas, which are the most fire-prone of all ecosystems and have the advantage of scientific understanding through a strong history of fire research, incorporation of fire into mine site rehabilitation has been problematic. Despite fires occurring every 1–3 years in the surrounding landscape, fire is often mistakenly excluded from rehabilitated mine sites in order, it is believed, to maximise vegetation growth. It is typically assumed that when local native plants are used in rehabilitation, the system will therefore be resilient to fire. In many cases, however, this is unlikely to be the case.

From the perspective of those who actively wish to exclude fire, the build-up of leaf litter on the soil surface of rehabilitated landscapes is viewed as a positive development. It is true that leaf litter protects the soil from extremes of temperature, from rain impact and from soil erosion, and can support the invertebrate diversity that leads to increases in soil organic matter. However, build-up of leaf litter is an increasing fire hazard. The rate of energy released by fire – fire intensity – increases with the fuel load, and higher intensity fires are more likely to kill the above-ground parts of trees. In the long-term absence of fire, leaf litter in rehabilitated sites can increase to many times the levels found in frequently burnt natural savanna (Figure 11.3).[11] Fire exclusion can thereby create a more serious fire management problem – when fires inevitably occur they can be very intense, killing most trees. Incorporation of fire from an early stage of the rehabilitation process is a more sustainable approach to managing fire hazard and conferring resilience to the ecosystem through management of the fuel load.



▸ ***Figure 11.3**: Changes in total fuel load with age of rehabilitation after bauxite mining at Gove, Northern Territory, on burnt sites and unburnt sites compared with unmined sites (ambient). The graph demonstrates that active burning programs are necessary to manage fuel loads.*[11]

Many mine site management plans view fires as emergencies to be managed. In rehabilitation, however, the key concern should be how quickly fires can be introduced into the rehabilitation process, and what the subsequent fire regime should be. These approaches require deeper consideration of the intensity, frequency and timing of fires.

The exclusion of fire from minesites undergoing restoration can lead to unusually high litter loads ***(a)****, which can then fuel destructive fires* ***(b)****. Photos: (a) Garry Cook, CSIRO; (b) Barbara McKaige, CSIRO.*

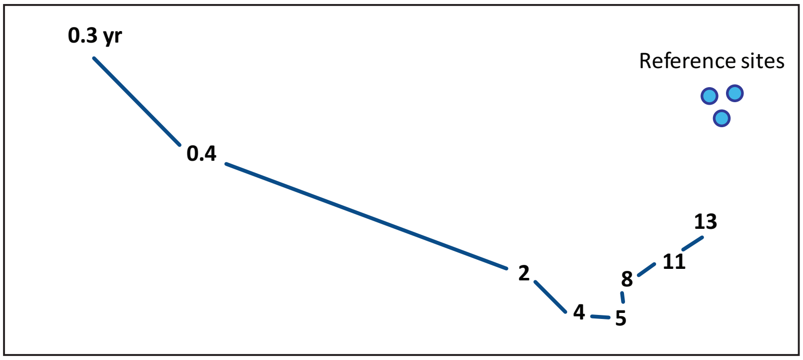
Assessing rehabilitation success

Another major challenge in mine site rehabilitation is the monitoring and assessment of success, which requires the development of reliable indicators of biodiversity and ecosystem health. One approach is landscape function analysis, which was originally developed as a tool for understanding and managing degradation in Australian rangelands.[12] Landscape function analysis supplements traditional approaches to vegetation monitoring by adding an interpretation that links vegetation structure closely with soil processes, such as water infiltration and run-off and nutrient cycling. The analysis uses rapid field techniques, the results of which are correlated with those of more detailed soil assessments.

Landscape function analysis has been expanded to ecosystem function analysis through the inclusion of vegetation composition and dynamics and habitat complexity, which are used as surrogates of biodiversity.[13] However, any measurement of soil or vegetation has a limitation as an indicator of biodiversity – at best it can indicate that the habitat is *potentially* suitable for fauna, but not that appropriate animal assemblages actually occur. An additional approach to monitoring and assessment is to use the occurrence of particular animal species as an indicator of rehabilitation success.

Invertebrate animals make excellent indicators of restoration because they are extremely abundant, play important roles in ecological processes that are crucial to restoration (such as soil formation and nutrient cycling), and are sensitive to environmental change. They may make good surrogates – if invertebrate communities are in good shape, then it may be safe to assume that the broader ecosystem is likewise. As the dominant faunal group throughout most of Australia, ants are commonly used as indicators of mine site rehabilitation.[14] Ant species change in a systematic way with increasing time since rehabilitation (Figure 11.4), and these patterns reflect those of other invertebrate groups and of important processes such as nutrient cycling.[15,16]

Anyone home? Ants are an ecologically dominant group throughout Australia, and are used in the mining industry as bio-indicators of mine site restoration. Photo: Alan Andersen, CSIRO.



► ***Figure 11.4***: *Ant recolonisation at rehabilitated mine sites of different ages at Ranger Uranium Mine in the Northern Territory. Numbers represent sites of different rehabilitation ages, with distances between them reflecting the similarity of ant species occurring at them (the closer together, the more similar). Ant species composition at sites of increasing age from a few months (left photograph) to four years (middle photograph) is increasingly similar to that at undisturbed reference sites (right photograph).[15] Photos: Alan Andersen, CSIRO.*

BIODIVERSITY OFFSETS

Mining will often have unavoidable negative impacts on biodiversity. In these cases, it is possible to offset impacts by creating benefits elsewhere so as to produce an overall conservation outcome that maintains the biodiversity assets of a region. Such offsets can be direct, through acquiring comparable land and managing it for biodiversity conservation, a process sometimes referred to as 'biobanking'. If mining has unavoidable impacts on habitat of particularly high quality, then the offset might require many times the area directly impacted.[17] Another form of a direct offset is through funding the implementation of regional conservation plans. Biodiversity offsets may also be indirect, such as by conducting relevant research for improved conservation management, or through education and training that increases regional capacity for biodiversity management.

Under the Environmental Offsets Policy of the *Environment Protection and Biodiversity Conservation Act 1999*, a minimum of 90% of offsets must be direct, except where greater benefits can be shown from indirect offsets, or where scientific uncertainty is high (such as in marine environments, as outlined below).[18] A stringent offset policy acts as a powerful incentive for limiting biodiversity loss in the first place. The *Arid Recovery* project is a partnership at Roxby Downs in South Australia between BHP Billiton, the local community, the South Australian Government and the University of Adelaide. Although not formally a mining offset project, *Arid Recovery* demonstrates many of the environmental and community benefits of such investment (Box 11.2).[19]

Offsets in the marine environment

The use of offsets in the marine environment offers challenges not encountered on land. In the first place, less is known about how resource development affects biodiversity and ecological function in marine ecosystems, given that impacts are frequently not visible to humans. The scope and scale of any offset requirement may therefore be uncertain. Second, there is often limited capacity for rehabilitating degraded marine sites because of the logistical difficulties of working under water, especially at depth. Third, ecological communities such as those occurring in the cold, low-energy deep sea typically have far slower rates of growth than those on land, and are unlikely to be able to be rehabilitated within a reasonable time-frame. Finally, even if an offset option could be identified, it is not legally possible in the marine environment for a company to purchase a site for habitat rehabilitation or to prevent others from subsequently re-damaging it. An alternative option for achieving marine offsets is to reduce or remove extractive pressures elsewhere, such as through the purchase of licences. These complex issues are formally recognised in the Environmental Offsets Policy of the *Environment Protection and Biodiversity Conservation Act 1999*, where the requirement for 90% direct offsets is not so rigidly applied in marine environments.[18]

Marine offsets requirements, therefore, have often not been so tightly coupled with the actual mining activity as they are on land. An example is provided by the Ichthys Project in north-

Box 11.2: The Arid Recovery project

BHP Billiton is the operator of Olympic Dam near Roxby Downs, one of Australia's largest mines. The *Arid Recovery* project aims to ensure that mining activity has a net positive impact on regional biodiversity assets. It has combined scientific research and monitoring with on-ground management to produce significant conservation benefits for threatened species.

Arid Australia has experienced severe loss of native mammals since European settlement, due to overgrazing by rabbits and domestic stock, and predation by cats and foxes. These forces have led to extinctions of most small- and medium-sized mammal species. *Arid Recovery* features a reserve of 123 km^2 with predator-exclusion fencing, supplemented by broader scale control of feral animals and ecosystem regeneration. Between 1998 and 2001, several regionally extinct mammal species – including the greater bilby, *Macrotis lagotis*; burrowing bettong, *Bettongia lesueur*; western barred bandicoot, *Perameles bougainville*; and greater stick-nest rat, *Leporillus conditor* – have been reintroduced into the reserve following feral animal control. Trial reintroductions are currently underway for other species such as the numbat, *Myrmecobius fasciatus*. The species have shown strong population growth, with, for example, the 30 burrowing bettongs initially released into the main exclosure growing to approximately 1000 by 2010.

Ongoing research and monitoring has shown that control of feral animals and species reintroductions have had a broader effect on biodiversity beyond threatened mammals. Burrowing by reintroduced bilbies and bettongs has promoted germination of seedlings and increased levels of soil carbon, and provided important shelter for other native mammals and reptiles. Freed from the impacts of introduced predators, many ground-nesting and ground-active birds have increased in abundance inside the reserve. The abundance of native nocturnal predatory birds has also increased, presumably in response to an increased food supply.

The Arid Recovery *project at Roxby Downs in arid South Australia has had benefits for threatened species, such as this burrowing bettong. Photo: Sam Secker,* Arid Recovery.

As well as providing a model for broad-scale restoration, *Arid Recovery* has made important contributions to our understanding of the ecology of arid Australia. The reserve includes different combinations of grazing, introduced predators and reintroductions, providing an opportunity for studying the effects of each of these factors. The project has demonstrated the role of introduced predators in causing extinctions of small mammals, while also uncovering some fascinating interactions that affect animal populations.[20] For example, reintroduction has been trialled for the woma, *Aspidites ramsayi*, a desert python that has declined in abundance throughout its range, but all nine reintroduced individuals were eaten by the native mulga snake, *Pseudechis australis*, within a few months. Similarly, trial reintroductions of numbats showed that these animals are highly susceptible to predation by native predatory birds.

western Australia, where the Inpex Corporation plans to pipe natural gas from the western edge of the Timor Sea nearly 900 km to Darwin Harbour for processing. Hence, the proponents have negotiated a coastal offsets program with the Northern Territory Government that includes habitat mapping for the Darwin Harbour region, conservation co-management of dugong, dolphins and marine turtles with Aboriginal communities, and an integrated marine monitoring and research program for Darwin Harbour.[21]

Dolphin conservation management is a feature of a marine offset project that compensates for potential environmental impacts of infrastructure development in Darwin Harbour. Photo: Carol Palmer.

CONCLUSION

Mining stands out from other major land uses in terms of the wealth it creates from the limited areas that it directly affects and the relatively short duration of the effect. This provides an opportunity for achieving high standards of environmental management, encompassing mitigation, ecosystem rehabilitation, and environmental offsets. In this chapter we have highlighted the importance of taking a regional approach to managing the cumulative impacts of multiple projects. In particular, infrastructure development in highly prospective regions can have reduced impacts if it is carefully planned on the basis of regional assessment, is conducted in advance of substantial capital investment, and is compensated for by offset activities where effects cannot be avoided or mitigated. Moreover, biodiversity offsetting can be used to promote conservation efforts in remote regions that would otherwise attract little conservation attention. Given the wealth created, it seems reasonable to expect and require mining to leave a legacy of enhanced biodiversity conservation at the national scale, despite any local losses.

FURTHER READING

Ludwig J, Tongway D, Hodgkinson K, Freudenberger D, Noble J (Eds) (1997) *Landscape Ecology, Function and Management: Principles from Australia's Rangelands*. CSIRO Publishing, Melbourne.

Majer JD (1989) *Animals in Primary Succession: The Role of Fauna in Reclaimed Lands.* Cambridge University Press, Cambridge.

Nicol T (2006) WA's mining boom: where does it leave the environment? *Ecos* **133**, 12–13.

Conclusions

Steve Morton and Andy Sheppard

Key messages

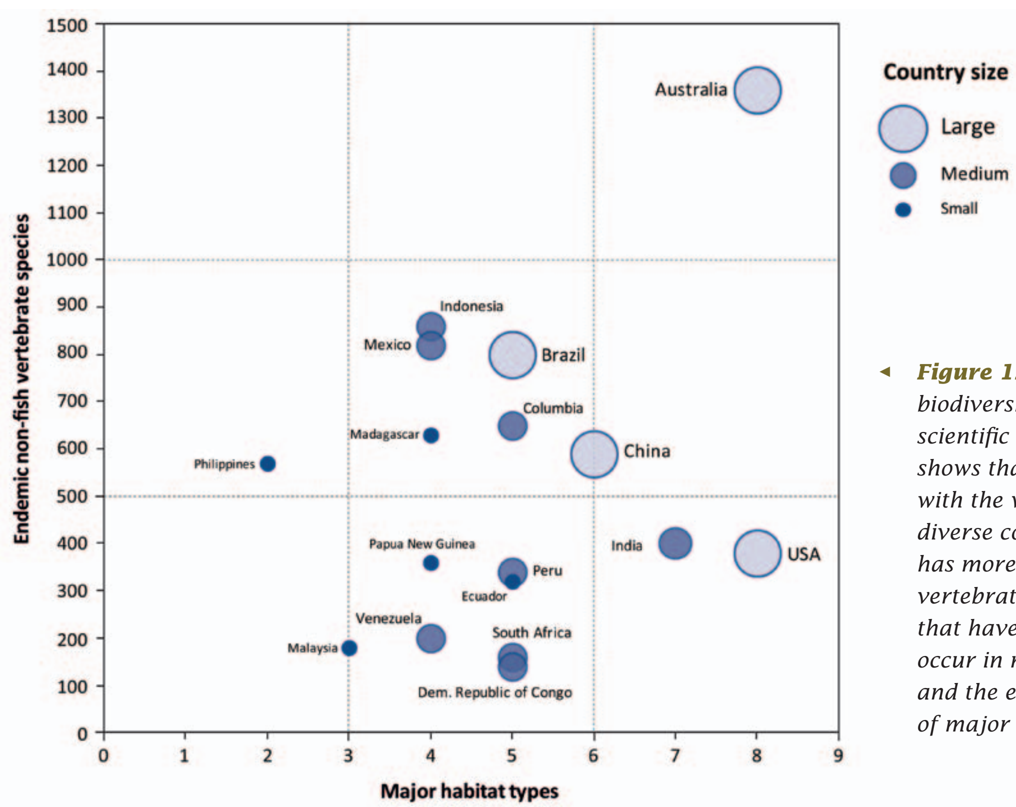
- Cultural and scientific values of Australia's biodiversity are globally significant.
- As the global demand for Australia's resources and agricultural products continues apace, and Australia's population continues to expand, pressure on all aspects of biodiversity will not diminish.
- Three key challenges stand out: science is still wrestling with the effective measurement of biodiversity; the undeniable evidence of significant biodiversity loss demands action; and managing biodiversity requires compromise because of the varied values that humans bring to their decisions.
- Science has a strong place in management, yet the scale and complexity of the challenge are such that biodiversity science is only just beginning to quantify ecological and social benefits and their interdependencies.
- In Australia, and globally, effective policy responses from governments to the inter-linked social and ecological aspects of biodiversity are still in the process of maturing.
- Five areas are identified where there is potential for substantial progress: fill key knowledge gaps; build community involvement; build national consensus on biodiversity priorities and establish performance measures for these in Australia's national accounts; institute a national program of biodiversity monitoring; and manage for resilience in the face of change.
- There are grounds for optimism in the face of these challenges, yet also a need for a greater effort to halt the decline in biodiversity.

AUSTRALIA'S BIODIVERSITY IN GLOBAL CONTEXT

Is Australian biodiversity unusual by world standards? The answer is yes and no! People here benefit economically from use of our biodiversity just as they do in other countries. Our society is also dependent upon the clean water, nutrient cycling and other forms of ecological life-support provided by ecosystems in similar fashion to nations elsewhere. And, like most other peoples, many of us cherish recreation in the bush. Given all that, though, it is evident that our biodiversity is distinctive for two reasons.

It is beyond doubt that our biodiversity is unusual by virtue of its unique scientific value to the world (Figure 12.1). This cargo of fellow Australians evolved to become what we see today during the tens of millions of years that the ancient continent of Gondwana was carried across the Indian and Pacific Oceans. On these grounds, Australia is truly special. For example:

- Australia is one of 17 'megadiverse' regions, among such naturally luxuriant countries as Brazil and the Congo.
- The heathlands and woodlands of south-western Australia comprise one of 34 biodiversity hotspots worldwide.
- Australia possesses more than 80 globally unique families of plants and animals.



◂ ***Figure 12.1****: Australia's biodiversity is of global scientific value. This figure shows that, when compared with the world's 17 mega-diverse countries, Australia has more endemic non-fish vertebrate species (species that have a backbone and occur in no other country), and the equal greatest number of major habitat types.*[1]

- Australia is home to half of the world's marsupial species.
- The continent is a centre for globally important plant families such as the Myrtaceae, which contains the gum-trees.
- Our suite of unusual or unique ecosystems is recognised in 15 World Heritage sites.
- Southern coastal near-shore marine ecosystems show distinctively high endemism and richness.
- Australian tropical reefs form part of the rich and complex ecosystem known as the 'coral triangle' of the south-west Pacific Ocean.

It is also indisputable that the cultural values of our biodiversity are unique. Australians are stewards of an entire continent, one of few nations so privileged. The nation's culture is now diverse and cosmopolitan, yet it continues to derive strength from the beaches, reefs, rainforests, the bush and the outback. Furthermore, Australia possesses a distinguishing element in its Aboriginal traditional ecological knowledge embedded in a globally unusual philosophy (Chapter 6). Few nations possess such an Indigenous heritage and its resultant biocultural diversity; it gives to the Australian landscape a unique human lustre.

But Australia is now an important part of the global community, providing resources of energy, minerals and food to an increasingly densely populated planet. We are no longer the isolated continent that was Gondwana, where biodiversity could evolve in relative isolation and where until very recently in geological time there was virtually no human population to affect or prey upon it. Indeed our own population growth presents new and continuing challenges to decision-makers and to our own value judgments, as well as those of our financial and commercial entrepreneurs and political leaders.

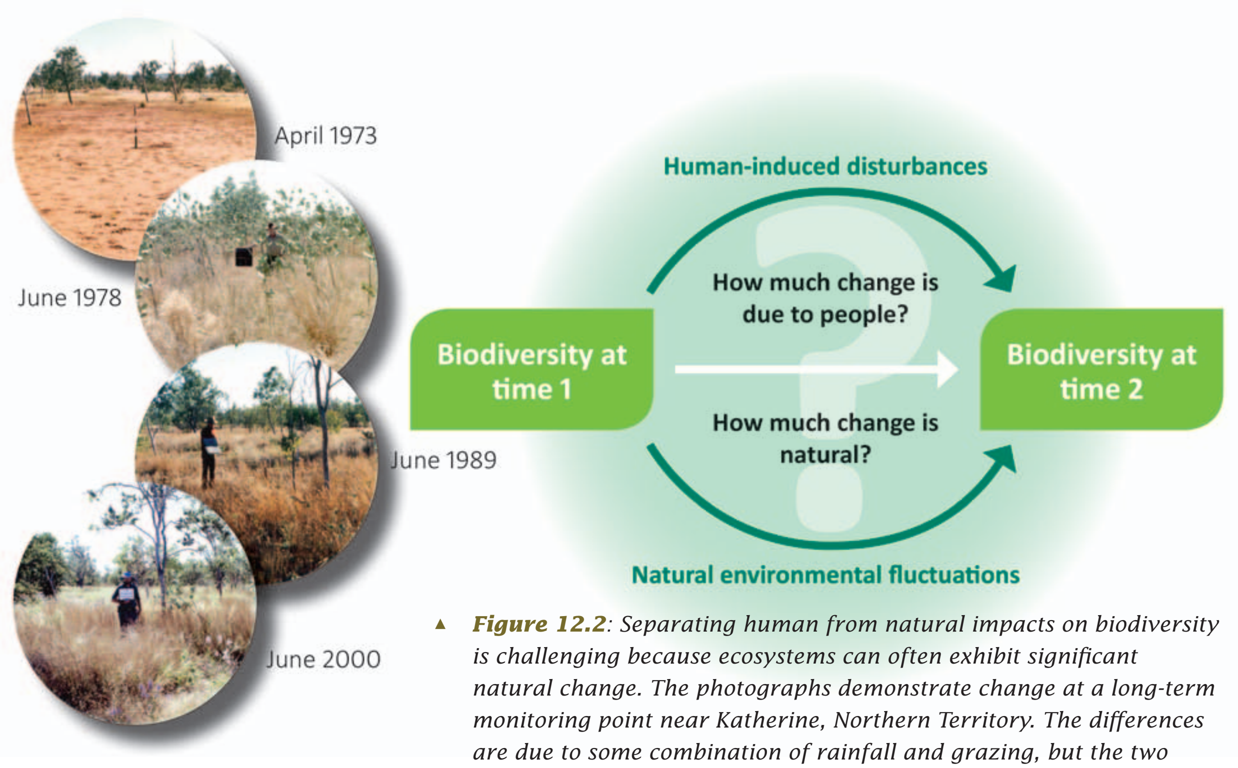
How then is the nation faring in its efforts to look after and build on these values of biodiversity?

The Great Barrier Reef, an ecosystem with globally significant values. Photo: Marie Davies.

BIODIVERSITY SCIENCE AND MANAGEMENT – EXTRAORDINARY COMPLEXITY AND CHALLENGE

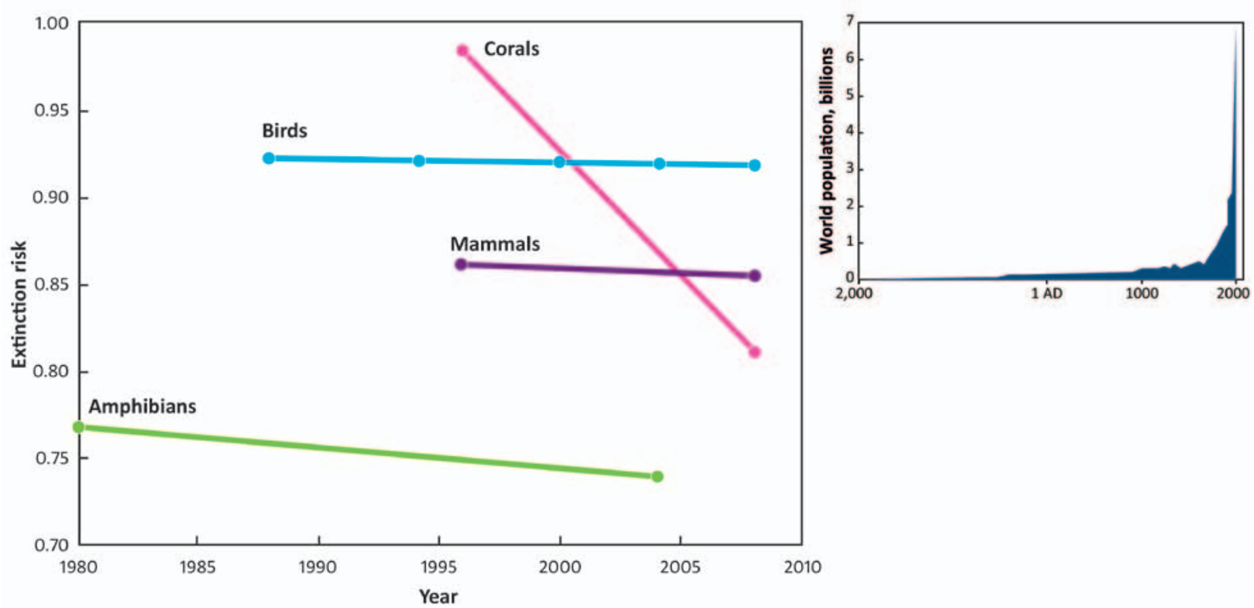
The scientific and management challenges in teasing out and making operational the concept of biodiversity are huge. Let us consider the objectives of biodiversity scientists and managers, and the hurdles that they face:

1. The first step is to describe and measure the full variety of life. Such an ambition is colossal. Calculations suggest that some 7–10% of the nine million species on Earth are found in Australia. Taxonomists are continuously discovering previously unrecognised species even among the flowering plants, birds and mammals, groups that are relatively well known. Among the vast arrays of insects, crustaceans and micro-organisms (just three poorly understood groups out of hundreds), myriads of species remain to be discovered (see Chapter 2). Within each species is a further level of genetic diversity that, in theory, would need to be outlined if biodiversity were to be comprehensively measured. Furthermore, this diversity ranges across land and sea in varying patterns to form ecosystems, which ecologists are still striving to categorise and measure in a scientifically systematic and repeatable way.
2. The desire to describe biodiversity is not an end in itself: the real objective is to understand its ebb and flow through time, so as to distinguish its response to human-induced disturbances from natural, background changes. The difficulty is that the natural world is far from stable. The 'balance of nature' is rare indeed; rather, ecosystems are mostly in constant flux. Separating natural fluctuations unambiguously from human influences is often difficult (Figure 12.2).



▲ ***Figure 12.2***: *Separating human from natural impacts on biodiversity is challenging because ecosystems can often exhibit significant natural change. The photographs demonstrate change at a long-term monitoring point near Katherine, Northern Territory. The differences are due to some combination of rainfall and grazing, but the two forces are not readily separable.[2] Photos: Gary Bastin, CSIRO.*

3. Next, scientists must present policy and management options to meet diverse expectations from society, so as to provide means of maximising benefits to people while minimising risks associated with biodiversity loss. Here, science is aiming to understand human dependencies on ecosystem services, and to find measures representing those benefits that will be useful for decision-makers. Although there are numerous examples of advances in biodiversity science, some of which are highlighted in this book, in this kind of measurement it has so far often fallen short.[3] Scientists too rarely have come to agreement on achievable and useful measures of biodiversity and its benefits because of the technical difficulties of such a complex challenge. The full concept of biodiversity is too rich to be lashed down by plain numbers, and yet aspects of it will have to be simplified and counted in order for us to understand what is going on.
4. The first three steps are challenging enough, yet they are being played out in a world undergoing a crisis of biodiversity decline. Biodiversity is partly a conceptual notion, an assertion encompassing diverse human values evident in the natural world. Nevertheless, the concept includes real things, among which there is undeniable evidence of a real problem of significant global and Australian decline. The rise in human population globally from 2 to 7 billion in just 100 years has caused this effect, directly or indirectly (Figure 12.3). Australian ecosystems have not been spared despite our relatively low human population. The continent has experienced, as Chapter 3 explains, the highest recent extinction rate among mammals of any country – 27 species in the last 200 years. This extinction process is a dismal by-product of land-use change and movement of species resulting from the conversion of natural to human-dominated ecosystems as people go about their lives. While there may be nothing inherently wrong in that process of conversion, we have made lots of irrevocable mistakes and have learnt that the benefits are also associated with risks. Indeed, the human species is now so dominant that the trade-off between our activities and the health of the natural world is becoming apparent to all. Future projections are also revealing that climates are likely to change so much and so fast that many species may not be able to persist where they currently live. Australia's biodiversity loss will probably not stabilise, therefore, and continuing change appears inevitable.
5. Finally, and in summary, the science and management of biodiversity are embedded in the inherently complex world of natural resource management. These endeavours have never been solely technical matters, because their emphasis is determined by the values that humans bring to their decisions – and with biodiversity the linkage between people and nature is especially critical. The chain of consequence may be summarised as follows.
   - Use of natural resources for human benefit causes alterations in an ecosystem.
   - Some species in that ecosystem decline and some ecosystem functions alter too; biodiversity, therefore, is usually seen to deteriorate from the viewpoint of one value system or another.



▲ ***Figure 12.3****: Growth in the human population (right graph) is leading, through resource use, to a global decline in biodiversity, known as the 'sixth great extinction event' in geological time. In the left graph, proportional declines in broad groups of plants and animals are estimated from a starting point of 1980. A value of 1 on the axis of 'extinction risk' indicates that all species in the group are assessed as being at little risk of going extinct in the near future; an index of 0 would mean that all species are extinct. If the lines on the graph were found to be sloping upwards after repeated assessment through time, then the rate of biodiversity loss would be reducing. However, most groups show a downward slope of increasing loss.*[4]

- Rarely is there an obvious point of ecological change, a threshold, at which particular values of biodiversity are at fatal risk (except sometimes for individual species).
- Resource use generates short-term returns: the benefits can be realised quickly, restoration is much more expensive, and the costs of biodiversity decline become obvious and occur only slowly.
- Science struggles to measure the changes in biodiversity effectively and concisely.
- Different members of society differ in their judgments of the appropriate balance between benefit and loss.
- Policy makers must then use imperfect information to compare apples (e.g. loss of spiritual benefits) with oranges (e.g. economic prosperity) to arrive at a compromise between the benefits of resource use and the disadvantages of change in biodiversity.

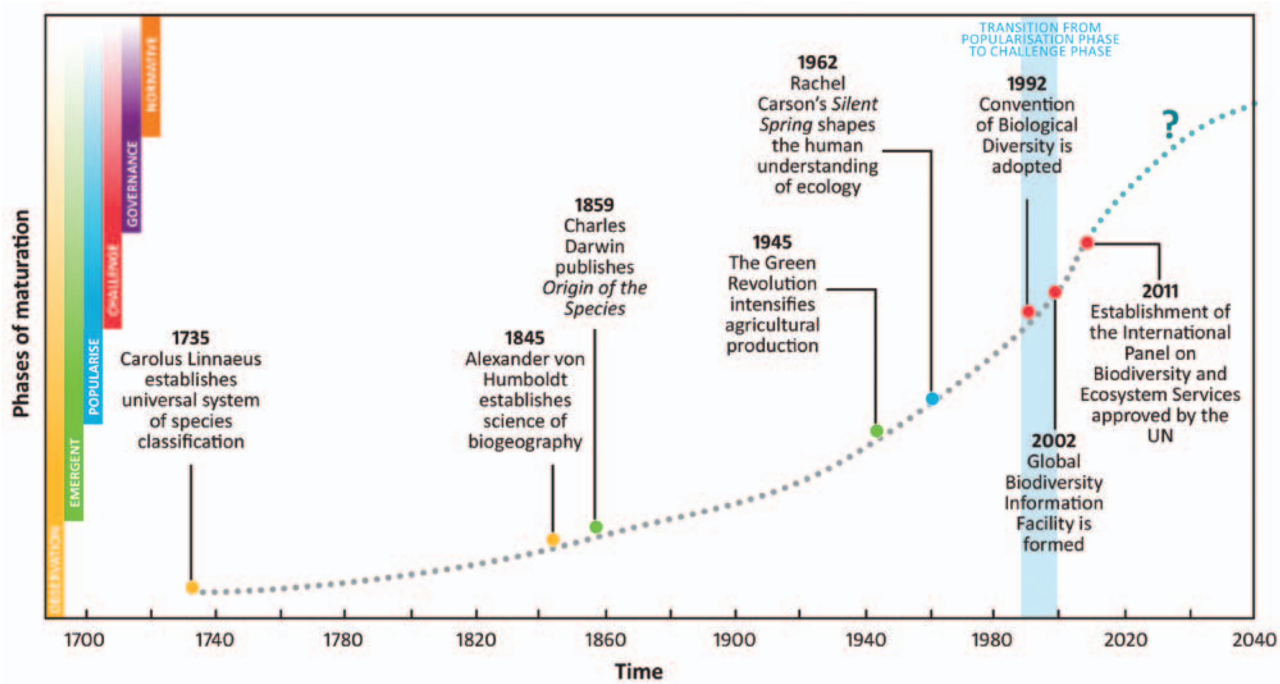
This sequence of events plays out often, all over the world. The authors of this book believe that we can do better at managing the consequences.

WAYS FORWARD

Humans are questing, striving animals: we will not abandon our ceaseless search for further advantage from resource use, and we will continue thereby to affect the planet and its biodiversity. The fact that Earth has entered an epoch of human domination is reflected in the coining by some scientists of a term, the 'Anthropocene', by analogy with Pleistocene and Pliocene ('anthropo' meaning human – the idea being that an observer in the far future looking at the geological and fossil record of the present times will find universal signals of human activity). Under these circumstances, biodiversity is almost certain to continue declining. The question is: 'How much loss will be acceptable according to the various values placed upon biodiversity among our community?'

The Anthropocene, the human-dominated world. Photo: Willem van Aken, CSIRO.

Many of the biodiversity challenges outlined in this book are the legacy of past decisions on the exploitation of natural resources, some of them ill-informed. It ought now to be clear that current decisions will similarly influence, often profoundly, the biodiversity to be inherited by our descendants. In the 21st century, we have the benefits of hindsight and of much greater scientific understanding of potential consequences of our decisions. This increases the urgency while raising the social and political costs of delay, and frequently causing contest and disagreement. The progress of the global societal response to major challenges through policy and management may be tracked through several generalised phases towards political maturation (Figure 12.4).[5] Biodiversity is at a critical juncture where society is not yet sufficiently convinced that biodiversity has been so severely compromised that action is demanded, with the result that corrective responses remain patchy.



▲ ***Figure 12.4****: The trajectory of biodiversity through six generalised phases by which policy and management respond to a topic of major social concern. The challenge of biodiversity decline has come through the first phase of observation, and then another of emergence into the social debate. Now it is part of popular discussion, but has not challenged societies sufficiently to proceed further into a phase where governance responses have significant impact. Other social developments, such as gender equality or workplace health and safety, have proceeded likewise through such phases, and when complete become part of the normal way in which things are done.*[5]

Nevertheless, growing concerns have led to establishment of an Intergovernmental Platform on Biodiversity and Ecosystem Services, an international body that will play a role analogous to the Intergovernmental Panel on Climate Change. In elucidating and reporting on biodiversity status and risks from change, it seeks to be a bridge between science and policy. Along with many nations Australia has also committed to the Convention on Biological Diversity, which has a specified set of objectives known as the 'Aichi Biodiversity Targets':[6]

Strategic Goal A. Address the underlying causes of biodiversity loss.

Strategic Goal B. Reduce the direct pressures on biodiversity and promote sustainable use.

Strategic Goal C. Improve biodiversity by safeguarding ecosystems, species and genetic diversity.

Strategic Goal D. Enhance the benefits to all from biodiversity and ecosystem services.

Strategic Goal E. Enhance implementation through participatory planning, knowledge management and capacity building.

There are several consequences of the struggle to arrive at effective societal responses. In the first place, the idea that there should be no further species losses locally and regionally is an impossible dream (although it seems sensible to strive for this outcome at the continental scale). There will always be winners and losers among species, ecosystems and values of biodiversity.

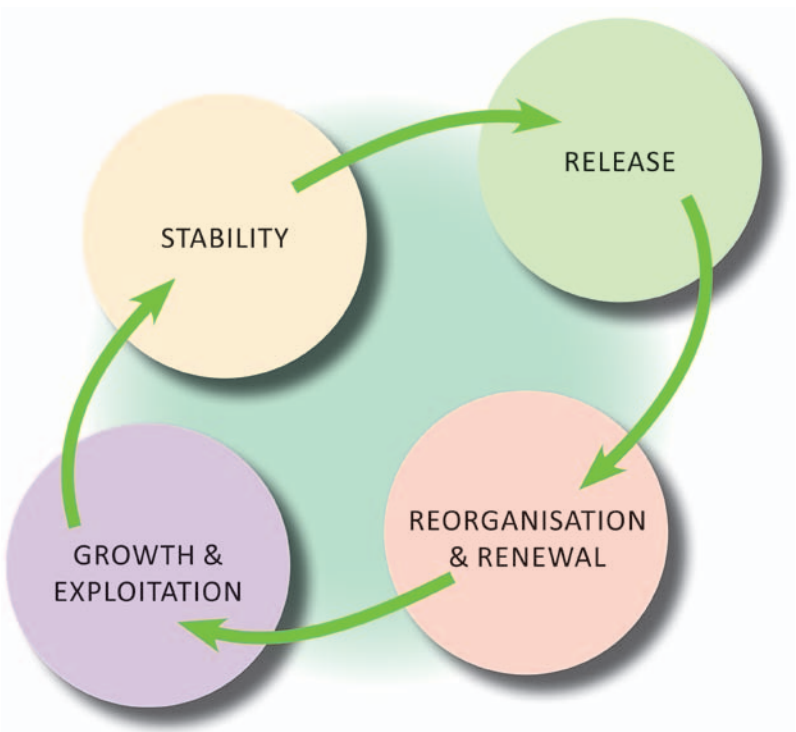
Science can also inform society about the probability of losing a species here or gaining more there, but rarely if ever can it say whether that result would be a 'good' or a 'bad' outcome across *all* the values that are represented in biodiversity. Nor should it, for this is a judgment that only society itself can make, through all the diverse mechanisms of democracy.

One option does not seem wise, though. Some land-based conservation activity springs from the assumption, whether spoken or not, that the goal is to recreate or to protect ecosystems as they were in a 'pristine' state in 1770, when Captain Cook arrived. The word 'pristine' is of limited meaning anyway, given the interaction between Aboriginal people and the continent's biodiversity in the millennia leading up to that moment in time. Nor will a 'pristine' baseline provide much guidance as climates change, probably irreversibly (Chapter 4). Our advice, rather, is that Australians embrace responsibility for deciding what we wish to achieve in various parts of our country. This recommendation emphasises the social aspect of biodiversity: it is up to us as Australians to ask ourselves what it is we wish our homeland to look like, with science helping to identify the options and understand how preferred options can be achieved most efficiently and with acceptable risk.

This book emphasises the concept of 'social technologies' as a method of reaching better decisions about how we manage biodiversity: which actions should be taken where and when in the land- or sea-scape, and in what form they are acceptable to society. Forms of structured decision-making (Chapter 4) can help solve the problem of allocation of effort between potential actions. Future progress rests upon having deeper conversations about societal goals for biodiversity, because achievement of a single goal will rarely satisfy all expectations. Approaches focused only on what ecosystems can do for humans in an economic sense would have no place for ecosystems or species without an immediate contribution to human wellbeing, and would leave Australia a poorer place culturally, recreationally and scientifically. Approaches that ignored economic need by emphasising primacy of the cultural and spiritual could likewise lead to poorer communities. Like many nations, we are trying to achieve a balance among values in our decision-making.

Community members debate options for natural resource management. Photo: Fiona Brown, CSIRO.

As biodiversity is a significant component of social–ecological systems, its management is likely to benefit from the emerging science of resilience thinking.[7] Resilience is the capacity of a system to absorb disturbance while retaining its functions and structure. Throughout this book it is argued that ecosystems are both complex and subject to unpredictable change. Such difficulties are even more pronounced in the social–ecological systems that end up defining the values of biodiversity around which we are striving to make decisions. To paraphrase the great philosopher of science JBS Haldane, social–ecological systems may not only be more complex than we imagine, they may be more complex than we *can* imagine. Under these conditions, resilience thinking suggests that we would do better by not trying to stabilise ecosystems, but rather to accept and work with the inevitable change (Figure 12.5).



▲ ***Figure 12.5***: *The cycle of growth, stability, release, and reorganisation undergone by social–ecological systems.*[7]

Resilience thinking rests upon the proposition that it is not possible to learn fully about nature without carrying out 'experiments'. Observations are important, of course, but they will not confidently tell us about cause and effect. And it is virtually impossible to do experiments at ecosystem scale without interacting with some form of human resource use. 'Adaptive management' is an approach that consciously approaches management decisions and actions *as an experiment*, with hypotheses, a design capable of producing data that may test the hypotheses, and an expectation that we will manage the system differently following the cycle of testing and understanding. Resilience thinking and adaptive management are essential ways forward.

A related approach is to use scenarios to explore potential futures, supported by computer models that reflect the dynamics of different systems and the interactions between systems. Exploring scenarios encourages the posing of important 'what if' questions while avoiding the temptation of imagining that the future will necessarily be like the recent past.[8] It is useful to be able to peer decades into the future and ask, for example, 'What kind of things could happen to biodiversity if Australia's human population continues to grow at the same rate and intense climate change occurs globally?', or 'What would it take to reverse declines in Australia's ecosystems while increasing agricultural output?' CSIRO is currently developing the modelling tools and expert systems for such approaches (Chapter 5), thereby highlighting the interdependence of biodiversity with society's changing demands for energy, water, food and reduced carbon emissions.[9] It would be foolish to suggest that scenarios make precise predictions of the future – that is not the aim. Instead, such modelling aims to understand the range of outlooks for Australian biodiversity and, thereby, to improve the quality of debate about what actions to take.

AUSTRALIA'S PERFORMANCE IN BIODIVERSITY MANAGEMENT

The *State of Environment Report 2011* confirmed that management of biodiversity in Australia is patchy:[10]

- Most of the pressures on biodiversity that arise directly or indirectly from human activities are still strong and will continue to be so in future years.
- Despite promising developments, pressures are not being substantially reduced nor the decline arrested.
- Climate change, population growth, economic development and consumption of natural resources must be managed better if the decline is to be arrested.
- Human activity has the potential to generate negative feedbacks that could harm the quality of life for Australians.

Impetus for improving management may be gained by focusing on the bright spots, five of which deserve attention. Each of these results from societal recognition, through an increasing acceptance of what science is telling us about the state of the environment, that there is a problem and that as a socially and technologically advanced society we can do something about it. Progress is being made.

The first is the improvement achieved through government leadership: broad-scale land clearing has been phased out, and processes have been set in place to restore high-biodiversity ecosystems as carbon sinks in anticipation of an increasingly carbon-based economy. State and Commonwealth governments are investing in community-driven, evidence-based natural resource management, and building strategies for biodiversity conservation on a vision of contributions by as many Australians as possible.

Second, in the last decade many global corporations and Australian companies have begun to mitigate the environmental impacts of their activities.[11] Businesses have as much potential to influence the course of events as governments, and in future will be fundamental to societal response to the decline in biodiversity. An exciting new opportunity is represented by the agricultural banking sector in Australia, which is exploring the contribution of biodiversity assets to the long-term sustainability and risk-management of farms.

Third is the quiet achievement of the expanding National Reserve System (Chapter 5), not only through government investment, but also increasingly with the growth in philanthropy through an increasing number of non-government conservation organisations supported by the public.[12]

Fourth, Australian marine management is world-leading. Fisheries management and spatial planning for marine reserves are among the best in the world.[13] Australia has pioneered the idea of adaptive management founded on conservation; despite the difficulties, the successes mean that our methods are in use worldwide (Chapter 9). Australia has contributed strongly in international marine policy, for example in managing the introduction of non-native marine species by shipping, and managing shared, migratory fish stocks on the high seas beyond national jurisdiction.[14]

A non-government conservation manager: Bush Heritage ecologist, Jim Radford, conducting a fauna survey at Boolcoomatta Reserve, north of Yunta, South Australia. Photo: Annette Ruzicka, Bush Heritage Australia.

Finally, the introduction of Native Title has provided opportunities for Indigenous Australians to return to their Country. Nearly 100 Indigenous ranger groups exist today, and more than 50 Indigenous Protected Areas contribute to the National Reserve System (Chapter 5). Close to a third of Australia's landmass is likely to be under Indigenous management by 2030.[15] The Commonwealth Government's long-term support for management of biodiversity in an Aboriginal framework is a visionary response to one of the cultural values highlighted at the beginning of this book, and is also helping improve Indigenous livelihoods.

In short, Australia has much to be pleased with, yet has extensive challenges to be concerned about. How might the future best be approached?

INTO THE FUTURE

One signal feature concerning the future stands out. Biodiversity will continue declining until Australian society acts to turn around the forces creating the problem. On the plus side, our society has considerable experience in conducting the social dialogue necessary for effective interaction between the community, policy-makers and science to such ends. Pointing out this positive feature of our national life does not imply that we always conduct the debates effectively or get the decisions right. There is a healthy level of discussion, though: a level of desire among governments to seek better balance between human activities and the breadth of values of biodiversity, and substantial national scientific expertise. There is good reason to believe that if any nation can mitigate the decline in biodiversity through social negotiation, it could be Australia. We are still very much the 'lucky country'.

Our population is small relative to the size of the continent, meaning that the financial base from which to resource this mitigation and restoration is also inherently limited. But, on the other hand, Australia has vast areas of healthy habitat and is starting to use its first-world capacity to combat errors of the past. We have a head start, and now practical programs, science and, increasingly, novel technical solutions will continue with the long-term task of maintaining functional ecosystems.

A further reason for optimism is that Australian research is at the global forefront in many relevant areas. We are leaders in rapid biodiversity assessment, remote sensing and sensor network technologies, spatial biodiversity analysis, fire management, restoration and rapid decision-making in the face of multiple values and limited data. We are also ahead of the game in landscape management, species reintroduction and translocation. Hence, Australia has increasing ability to provide effective management.

In light of these features – rapid and ongoing biodiversity decline, experience in social dialogue, and substantial national scientific expertise – this book offers the following suggestions for big steps forward. They emerge from our experiences at working in biodiversity science and in writing the book: five top potential advances that seem to offer the greatest promise.

1. Fill key knowledge gaps. Quantify Australian species and their interactions before threats are too widespread, and especially develop better understanding of the potential impacts of climate change on biodiversity values at land and sea.[16]
2. Strengthen community involvement. Dialogue will allow communities to make better environmental decisions in matters such as biodiversity transactions, incentives and market instruments such as offsets, bio-banking and stewardship programs.
3. Build national consensus on biodiversity priorities and establish performance measures for these in Australia's national accounts. If environmental resources and ecosystem services, including biodiversity, were to be measured and tracked in a similar manner to our economy, then more effective management and accountability would follow.

4. Institute a national program of biodiversity monitoring. If biodiversity assets are to become part of the national accounts, then monitoring must occur, just as with economic data; the many automated technologies being developed will assist.
5. Manage for resilience in the face of change. We will need innovative adaptive management of vital ecosystem functions, given that biodiversity will progressively alter within our lifetimes due to climate change and existing long-standing pressures.

In closing, we write briefly from our perspectives as scientists whose value systems emphasise the ecological life-support benefits of biodiversity in addition to the scientific treasures that, obviously, we cherish. The challenges we have outlined are real indeed. Australia is on a trajectory of continuing declines in biodiversity (in line with most countries of the world), as the sweeping changes bringing about the Anthropocene create a new world. The country inherited by future citizens could reflect merely a haphazard collection of opportunistic species if our present actions are unplanned. On the other hand, we have the potential to choose a future for our biodiversity – to 'design' our landscapes – if we put our collective minds to it and act with caution. It is in this sense that every decision on natural resource management is a choice, as explained in Chapter 4. Sometimes, too, looking after biodiversity would not be that hard financially given the science we have available, if that was our priority. We write with a sense of urgency that these matters be debated in society and acted on. In our view, society needs to move into the normative stage of recognising that managing biodiversity for the long term is a core activity of our culture (Figure 12.4).

This book is based on the proposition that societal support for future choices will be enhanced if those decisions can be informed by science. Our writers also believe that the extent of the continuing challenges in biodiversity will motivate contributions from future generations of Australian scientists. Science will increasingly provide options for the diverse values held across society so as to enhance a reasoned debate and, in time, enable progress towards a healthy future for our unique Australian landscape.

FURTHER READING

Lindenmayer D, Dovers S, Harriss Olson M, Morton S (2008) *Ten Commitments: Reshaping the Lucky Country's Environment*. CSIRO Publishing, Melbourne.

Steffen W, Burbidge AA, Hughes L, Kitching R, Lindenmayer D *et al.* (2009) *Australia's Biodiversity and Climate Change*. Australian Government Department of Climate Change, Canberra.

Glossary

Abundance: in the ecological sense, usually refers to the number of individuals or amount of biomass of a species in a particular ecosystem.

Adaptive management: a systematic process to improve decision-making in the face of uncertainty. The process involves a cycle of planning, taking action, evaluating the results of the action, and then taking further action based on the results of that evaluation.

Arid: used to describe an area or climate that lacks moisture.

Assemblage: a collection of plants and/or animals that characteristically occur within a particular environment or habitat.

Biodiversity: the variety of all living organisms on Earth and at all levels of organisation, including the diversity of the genetic material within each species and the diversity of ecosystems that those species make up, as well as the ecological and evolutionary processes that keep them functioning and adapting.

Biodiversity footprint: see footprint.

Biodiversity hotspots: see hotspot.

Biodiversity offsets: see offsets.

Biomass: the total mass of living matter within a given area or volume.

Biomes: regions with similar weather and similar types of plants and animals. There are land biomes (sometimes called habitats), such as rainforest, desert and temperate forest, and freshwater and marine biomes, such as wetlands and coral reefs.

Bioregions: areas smaller than a biome (see above) that are geographically distinct areas of land with common characteristics, such as geology, landform patterns, climate, ecological features, and plant and animal communities. Australia has been formally mapped into 89 distinct bioregions.

Biota: the living organisms of a particular region, habitat or geological period.

Community: similar to the human variety, when used in an ecological sense a community is a unit composed of a group of plants and animals occupying a particular area, usually interacting with each other and their environment.

Connectivity: a measure of the extent to which components of a network (such as habitats or areas of native vegetation) are connected to one another, and the ease with which they can make these connections.

Corridor: an area of habitat that connects wildlife populations that would otherwise be separated by barriers such as roads, development, or open land.

Dispersal: the permanent movement of a species to a new area, such as when an animal moves from the place where it was born to a breeding site, or from one breeding site to another, or when seeds are redistributed away from the parent plant. Dispersal is not to be confused with migration, which is a seasonal rather than permanent movement.

Distribution: the geographical range of locations in which a species is found.

Diversity: the number and variety of the item of interest (such as species, genes or ecosystems) found within a specified region. When we measure diversity we have to take account of not only the number of different species present in a place, but also their proportional abundances. For example, a sample of three species of similar abundance is more diverse than a sample where one of the three species is much more abundant than the others.

Ecological footprint: see footprint.

Ecosystem: a biological community made up of a complex network of interactions between organisms and their physical environment.

Ecosystem functions: biological processes that control the transfer of energy, nutrients and organic matter through an environment; examples include primary production, by which plants use sunlight to convert inorganic matter into new biological tissue; nutrient cycling, by which nutrients are captured, released and then recaptured; and decomposition, by which dead plants and animals are broken down and recycled into inorganic matter.

Ecosystem services: the important benefits that humans gain from healthy functioning ecosystems. The benefits are often classified into four kinds: (1) supporting services are ecosystem services, such as seed dispersal, that are necessary for the production of other services; (2) provisioning services involve the production of resources, such as fresh water; (3) regulating services are those that lessen undesirable environmental change, such as pest and disease control; and (4) cultural services are the benefits people obtain from ecosystems through recreation, aesthetic and spiritual experiences.

Endangered: used to describe a species that is facing a very high risk of extinction in the wild in the near future.

Endemic: when a species is endemic to an area, we mean it is found only in that area, although it did not necessarily originate there.

Endemism: the extent to which a species is restricted to a particular area. High endemism means the species is found in few, if any, other locations.

Environmental footprint: see footprint.

***Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)**: the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places – defined in the EPBC Act as matters of national environmental significance (www.environment.gov.au/epbc).

Extinction: a state when there is no reasonable doubt that the last member of a species has died. This can refer either to total extinction across the species' range or extinction in part of the range where the species was previously present.

Fire regime: the pattern, frequency and intensity with which fire occurs in a given area over an extended period of time.

Footprint: the total impact, both direct and indirect, that the human population has while going about our daily lives, including the impacts of what we build and consume, and of the waste we produce.

Fragmented/fragmentation: the dividing of habitat areas into smaller areas or fragments, separated by different habitat types. This can be a result of geological processes or changes in climate that slowly alter the environment, or human activity, such as changes in land use.

Genera: the plural of the taxonomic category genus, which is a group of species exhibiting similar characteristics. For example, red kangaroos (*Macropus rufus*) and eastern grey kangaroos (*Macropus giganteus*) are individual species that are members of the same genus, *Macropus*.

Genomics: the study of structure, function, evolution and mapping of an organism's genetic material.

Gondwana: the name of the southern hemisphere supercontinent that broke into pieces during continental drift to yield today's South America, Antarctica, Australia, New Guinea, New Zealand, India, Africa, and much of Indonesia.

Habitat connectivity: see connectivity.

Habitat fragmentation: see fragmentation.

Hotspot: area with a high diversity of plants and animals, and highly valued ecosystems.

Indigenous Protected Areas: an area of Indigenous-owned land or sea where traditional owners have entered into an agreement with the Australian Government to promote biodiversity and cultural resource conservation. Indigenous Protected Areas make up over a third of Australia's National Reserve System.

Invasive species: a species occurring outside its usual range, and which adversely affects the economy, environment, or human health. Note that there are species regarded as native to Australia that are becoming invasive, but these are still a comparatively minor part of the invasive problem.

Larvae: the active, immature forms of an animal.

Larval: used to describe something in an immature state.

Lineage: a group composed of species that have descended from a common ancestor; a branch on an evolutionary tree. A lineage might have one or many living 'tips' on the branch; for example, platypus and echidnas are two 'tips' of the monotreme mammals' lineage.

Marine Protected Area: parts of the ocean that are managed primarily for the conservation of their ecosystems, habitats, and the marine life they support.

Metagenomics: the study of genetic material recovered directly from environmental samples (such as soil or water samples) and, therefore, containing many kinds of organisms. It is revolutionising the study of microbial communities, but it has potential uses for multicellular organisms as well.

National Reserve System: Australia's network of protected areas. It is made up of Commonwealth, state and territory reserves, Indigenous lands, and protected areas run by non-profit conservation organisations, as well as ecosystems protected by farmers on their private working properties.

Naturalised: used to describe species that are capable of surviving and reproducing in an area where they are non-native.

Novel ecosystem: a combination of biological entities, patterns and processes that has not occurred before (generally having arisen because of human activities), and has no naturally occurring counterparts.

Offsets: conservation activities undertaken in one location, which have been paid for by a developer to compensate for negative biodiversity impacts in another location.

Plankton: organisms that drift in the water column because they are incapable of swimming against a current (including algae, bacteria, and many animals such as crustaceans and jellyfish).

Radiation: the diversification by evolution of species from a common ancestor. For example, 'the radiation of marsupials in Australia' refers to the tremendous diversity of marsupial groups and the many species within each group.

Rangelands: vast open landscapes of native grasslands, shrublands and woodlands.

Remnant: patches of original native vegetation remaining after conversion of landscapes to other uses, such as agriculture or urban settlement.

Resilience: the capacity of an ecosystem to recover from shocks, such as fire, flood and clearing.

Richness: in ecology, refers to the number of species in a given area.

Riparian: describes the area on the banks of a river or other body of water.

Savanna: a flat grassy plain in tropical and subtropical regions, with few trees.

Speciation: the formation of new and distinct species in the course of evolution, usually by the division of a single species into two or more genetically distinct species.

Species: a group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding. Species is the taxonomic rank below genus and above subspecies.

Species abundance: see abundance.

Species diversity: see diversity

Species richness: see richness.

Status: of a species, usually refers to whether there are still living members and how likely it is to become extinct in future.

Surrogate: a substitute. In this book it refers particularly to an environmental variable used to represent some other variable that is more difficult to measure.

Terrestrial: occurring on land, as distinguished from freshwater and marine ecosystems.

Temperate: a region or climate characterised by mild temperatures.

Threatened: denotes when a native species is at risk of extinction in the wild in the future.

Trend: the general direction in which a species' status is changing.

Tropics: the region between the tropics of Cancer and Capricorn; that is, the area between latitude 23°26' north and 23°26' south.

Weed: generally indicates a plant that is unwanted. In the context of biodiversity conservation, weeds and exotic plants are often used interchangeably.

Wet Tropics: a United Nations World Heritage-listed site stretching along some 450 km of the Queensland's north-east coast and consisting of approximately 8944 km^2 of tropical rainforest.

Endnotes

Chapter 1

1 Mora C, Tittensor DP, Adl S, Simpson AGB, Worm B (2011) How many species are there on earth and in the ocean? *PLoS Biol* **9**, e1001127. doi:10.1371/journal.pbio.100112; this estimate may not yet include the full but unknown diversity of microbes.

2 Ladiges P, Evans B, Saint R, Knox B (2010) *Biology: An Australian Focus*. McGraw-Hill, Sydney.

3 Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-Being: Synthesis*. Island Press, Washington, DC. <http://www.millenniumassessment.org/en/index.html>.

4 Farnham TJ (2007) *Saving Nature's Legacy: Origins of the Idea of Biological Diversity*. Yale University Press, New Haven, CT.

5 Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C *et al.* (2012) Biodiversity loss and its impact on humanity. *Nature* **486**, 59–67.

6 TEEB (2010) *The Economics of Ecosystems and Biodiversity. Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.* <http://www.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf>.

7 Collins SL, Carpenter SR, Swinton SM, Orenstein DE, Childers DL *et al.* (2011) An integrated conceptual framework for long-term social–ecological research. *Frontiers in Ecology and Environment* **9**, 351–357.

8 Gorenflo LJ, Romaine S, Mittermeier RA, Walker-Painemilla K (2012) Co-occurrence of linguistic and biological diversity in biodiversity hotspots and high biodiversity wilderness areas. *Proceedings of the National Academy of Sciences* **109**, 8032–8037.

9 Hill R, Cullen-Unsworth LC, Talbot LD, McIntyre S (2011) Empowering Indigenous peoples' biocultural diversity through world heritage cultural landscapes: a case study from the Australian tropical forests. *International Journal of Heritage Studies* **17**, 571–590.

10 Hill R, Pert PL, Davies J, Robinson CJ, Walsh F, Falco-Mammone F (2013) *Indigenous Land Management in Australia. Extent, Scope, Diversity, Barriers and Success Factors*. CSIRO Ecosystem Sciences, Cairns. <http://www.daff.gov.au/__data/assets/pdf_file/0010/2297116/ilm-report.pdf>.

Chapter 2

1 Veevers JJ (2006) Updated Gondwana (Permian–Cretaceous) earth history of Australia. *Gondwana Research* **9**, 231–260; Veevers J, Powell C, Roots S (1991) Review of seafloor spreading around Australia: synthesis of the patterns of spreading. *Australian Journal of Earth Sciences* **38**, 373–389.

2 Cox CB, Moore PD (1985) *Biogeography: An Ecological and Evolutionary Approach.* 4th edn. Blackwell Scientific Publications, London.

3 Battley P, McCaffery B, Rogers D, Hong J-S, Moores N *et al.* (2010) *Invisible Connection:*

Why Migrating Shorebirds Need the Yellow Sea. CSIRO Publishing, Melbourne.

4 Byrne M, Steane D, Joseph L, Yeates D, Jordan G *et al.* (2011) Decline of a biome: evolution, contraction, fragmentation, extinction and invasion of the Australian mesic zone biota. *Journal of Biogeography* **38**, 635–656; Metcalfe D, Ford A (2008) Floristics and plant biodiversity of the rainforests of the Wet Tropics. In *Living in a Dynamic Tropical Forest Landscape* (Eds N Stork, SM Turton) pp. 123–131. Blackwell Publishing, Melbourne.

5 Oliver PM, Sanders K (2009) Molecular evidence for multiple ancient lineages: ancient Gondwanan origins of a diverse Australian gecko radiation. *Journal of Biogeography* **36**, 2044–2055.

6 Phillips MJ, Gibb GC, Crimp EA, Penny D (2010) Tinamous and moa flock together: mitochondrial genome sequence analysis reveals independent losses of flight among ratites. *Systematic Biology* **59**, 90–107.

7 Last P, Gledhill D (2007) The maugean skate, *Zearaja maugeana* sp. nov. (Rajiformes: Rajidae) – a micro-endemic, Gondwanan relict from Tasmanian estuaries. *Zootaxa* **1494**, 45–65.

8 Crisp M, Burrows G, Cook L, Thornhill A, Bowman D (2010) Flammable biomes dominated by eucalypts originated at the Cretaceous–Palaeogene boundary. *Nature Communications* **2**, 193. doi:10.1038/ncomms1191

9 Byrne M, Yeates DK, Joseph L, Kearney M, Bowler J *et al.* (2008) Birth of a biome: insights into the assembly and maintenance of the Australian arid zone biota. *Molecular Ecology* **17**, 4398–4417.

10 Catullo R, Doughty P, Roberts JD, Keogh S (2011) Multi-locus phylogeny and taxonomic revision of *Uperoleia* toadlets (Anura: Myobatrachidae) from the western arid zone of Australia, with a description of a new species. *Zootaxa* **2902**, 1–43.

11 Potter S, Eldridge MB, Taggart D, Cooper S (2012) Multiple biogeographical barriers identified across the monsoon tropics of northern Australia: phylogeographic analysis of the *brachyotis* group of rock-wallabies. *Molecular Ecology* **21**, 2254–2269.

12 Butler A, Rees T, Beesley P, Bax N (2010) Marine biodiversity in the Australian region. *PLoS ONE* **5**, e11831. doi:10.1371/journal.pone.0011831

13 Strahan R, Van Dyck S (Eds) (2008) *Mammals of Australia*. New Holland Publishers, Sydney.

14 Zborowski P, Edwards E (2007) *A Guide to Australian Moths*. CSIRO Publishing, Melbourne.

15 Schodde R, Tidemann S (Eds) (1986) *Reader's Digest Complete Book of Australian Birds*. Reader's Digest Services, Sydney.

16 Andersen A, Jacklyn P, Dawes-Gromadzki T, Morris I (2005) *Termites of Northern Australia*. Barker Souvenirs, Alice Springs.

17 Shattuck S (2000) *Australian Ants: Their Biology and Distribution*. CSIRO Publishing, Melbourne.

18 Kondo T, Crisp M, Linde C, Bowman D, Kawamura K *et al.* (2012) Not an ancient relic: the endemic *Livistona* palms of arid central Australia could have been introduced by humans. *Proceedings of the Royal Society B* **279**, 2652–2661. doi:10.1098/rspb.2012.0103

19 Last P, Stevens J (2009) *Sharks and Rays of Australia*. CSIRO Publishing, Melbourne.

20 Chilton NB, Huby-Chilton F, Beveridge I, Smales LR, Gasser RB, Andrews RH (2011) Phylogenetic relationships of species within the tribe Labiostrongylinea (Nematoda: Cloacinidae) from Australian marsupials based on ribosomal DNA spacer sequence data. *Parasitology International* **60**, 381–387; Flannery TF (1989) Phylogeny of the Macropodoidea: a study in convergence. In *Kangaroos, Wallabies and Rat-kangaroos* (Eds G Grigg, P Jarman, I Hume) pp. 1–46. Surrey Beatty and Sons, Sydney.

21 Johnson C (2006) *Australia's Mammal Extinctions: A 50,000-year History*. Cambridge University Press, Cambridge, UK.

22 Cooper W, Cooper WT (2004) *Fruits of the Australian Tropical Rainforest*. Nokomis Editions, Melbourne; Drew A, Spencer HJ (1998) Consumption of *Idiospermum australiense* seeds by the musky rat kangaroo, *Hypsiprymnodon moschatus* (Marsupialia: Potoroidae). *Memoirs of the Queensland Museum* **42**, 438.

23 Jones DL (2006) *Native Orchids of Australia*. Reed New Holland, Sydney.

24 Aplin K, Fitch A, King D (2006) A new species of *Varanus* Merrem (Squamata: Varanidae) from the Pilbara region of Western Australia, with observations on sexual dimorphism in closely related species. *Zootaxa* **1313**, 1–38; Couper P, Melville J, Emmott A, Chapple S (2012) A new species of *Diporiphora* from the Goneaway Tablelands of Western Queensland. *Zootaxa* **3556**, 39–54; Donnellan S, Anstis M, Price L, Wheaton L (2012) A new species of *Crinia* (Anura: Myobatrachidae) from the Flinders Ranges, South Australia. *Zootaxa* **3499**, 1–26; Donnellan S, Mahony M, Bertozzi T (2012) A new species of *Pseudophryne* (Anura: Myobatrachidae) from the central Australian ranges. *Zootaxa* **3476**, 69–85; Doughty P, Maryan B, Donnellan S, Hutchinson M (2007) A new species of taipan (Elapidae: *Oxyuranus*) from central Australia. *Zootaxa* **1422**, 45–58; Doughty P (2011) An emerging frog diversity hotspot in the northwest Kimberley of Western Australia: another new frog species from the high rainfall zone. *Records of the Western Australian Museum* **26**, 209–216; Hoskin C (2012) Two new frog species (Microhylidae: *Cophixalus*) from the Australian Wet Tropics region, and redescription of *Cophixalus ornatus*. *Zootaxa* **3271**, 1–16; Hoskin C, Aland K (2011) Two new frog species (Microhylidae: *Cophixalus*) from boulder habitats on Cape York Peninsula, north-east Australia. *Zootaxa* **3027**, 39–51; Kay G, Keogh S (2012) Molecular phylogeny and morphological revision of the *Ctenotus labillardieri* (Reptilia: Squamata: Scincidae) species group and a new species of immediate conservation concern in the southwestern Australian biodiversity hotspot. *Zootaxa* **3390**, 1–18; Mecke S, Doughty P, Donnellan S (2013) Redescription of *Eremiascincus fasciolatus* (Günther, 1867) (Reptilia: Squamata: Scincidae) with clarification of its synonyms and the description of a new species. *Zootaxa* **4701**, 473–517; Oliver P, Doughty P, Palmer R (2012) Hidden biodiversity in rare northern Australian vertebrates: the case of the clawless geckos

(*Crenadactylus*, Diplodactylidae) of the Kimberley. *Wildlife Research* **39**, 429–435.

25 Humphreys WF (2008) Rising from down under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* **22**, 85–101.

26 Last PR, Gledhill DC (2009) A revision of the Australian handfishes (Lophiiformes: Brachionichthyidae), with descriptions of three new genera and nine new species. *Zootaxa* **2252**, 1–77.

27 Gillanders BM, Payne NL (2013) Giant Australian cuttlefish. In *Natural History of Spencer Gulf* (Eds S Madigan, SA Shepherd, S Murray-Jones, D Wiltshire). Royal Society of South Australia, Adelaide (in press).

28 Nelson L, Scheffer SJ, Yeates DK (2012) Species diversity of *Fergusonina* Malloch gall flies (Diptera: Fergusoninidae) forming leaf bud galls on snow gum (*Eucalyptus pauciflora* Sieb. ex Spreng. complex), with a description of a new species from Tasmania. *Insect Systematics and Evolution* **43**, 147–160.

Chapter 3

1 <http://www.environment.gov.au/system/files/resources/17345e0a-40dc-4cae-97d3-e972c52c4ea7/files/vegfsheet-mvg5.pdf>

2 Australian Government Department of Environment and Water Resources (2007) *Australia's Native Vegetation: A Summary of Australia's Major Vegetation Groups*. Australian Government Department of Environment and Water Resources, Canberra. <http://www.environment.gov.au/erin/nvis/publications/major-veg-summary.html>.

3 Australian Government Department of Sustainability, Environment, Water, Population and Communities (2011) *Australia State of the Environment Report 2011*. <http://www.environment.gov.au/soe/2011/index.html>.

4 Chapman AD (2009) *Numbers of Living Species in Australia and the World*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra.

5 <http://www.ala.org.au>

6 Australian Government Department of the Environment, Water, Heritage and the Arts, 2008. *Assessment of Australia's Terrestrial Biodiversity*. <http://www.environment.gov.au/biodiversity/publications/terrestrial-assessment/index.html>.

7 Queensland Government Department of Environment and Heritage Protection (2011) *Endangered Plants*. Department of Environment and Heritage Protection, Brisbane. <http://www.ehp.qld.gov.au/wildlife/threatened-species/endangered/endangered-plants/index.html>; Bostock PD, Holland AE (Eds) (2007) *Census of the Queensland Flora 2007*. Queensland Herbarium, Environmental Protection Agency, Brisbane.

8 New South Wales Government Department of Environment and Heritage (2012) *Threatened Species Conservation Act Schedules 1, 2 and 3*. NSW Scientific Committee, Department of Environment and Heritage, Sydney. <http://www.environment.nsw.gov.au/resources/nature/TS20120504.pdf>; New South Wales Government Department of Environment and Heritage (2012) *NSW*

Weeds. Department of Environment and Heritage, Sydney. <http://www.environment.nsw.gov.au/pestsweeds/nswweeds.htm>.

9 Victorian Government Department of Sustainability and Environment (2012) *Flora and Fauna Guarantee Act 1988, Threatened List*. Department of Sustainability and Environment, Melbourne. <http://www.depi.vic.gov.au/environment-and-wildlife/threatened-species-and-communities/flora-and-fauna-guarantee-act-1988/ffg-listed-taxa-communities-and-potentially-threatening-processes>. Page last updated July 2012 [cited 15 Aug 2012]; Spencer R (2006) *Garden Plants as Environmental and Agricultural Weeds*. Royal Botanic Gardens Board, Melbourne. <http://www.rbg.vic.gov.au/__data/assets/word_doc/0005/16466/WEEDS-DRAFT-LATEST.doc>.

10 South Australian Government Department of Environment, Water and Natural Resources (2011). *Threatened Plant Species*. Department of Environment, Water and Natural Resources, Adelaide. <http://www.environment.sa.gov.au/Plants_Animals/Threatened_species_and_ecological_communities/Threatened_species/Threatened_plant_species>; Biosecurity SA (2013) *Weeds and Pest Animals*. Government of South Australia, Adelaide. <http://www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity/weeds>.

11 Northern Territory Government Department of Natural Resources, Environment, the Arts and Sport (2012) *Threatened Species List*. Department of Natural Resources, Environment, the Arts and Sport, Darwin. <http://www.nretas.nt.gov.au/plants-and-animals/animals/home/specieslist>; Short PS, Albrecht DE, Cowie ID, Lewis DL Stuckey B (Eds) (2011) *Checklist of the Vascular Plants of the Northern Territory*. Northern Territory Herbarium, Department of Natural Resources, Environment, the Arts and Sport, Darwin. <http://lrm.nt.gov.au/data/assets/pdf_file/0010/11017/200701ntchecklist.pdf>.

12 Tasmanian Government Department of Primary Industries, Parks, Water and Environment (2012) *List of Threatened Species*. Department of Primary Industries, Parks, Water and Environment, Hobart. <http://dpipwe.tas.gov.au/conservation/threatened-species/lists-of-threatened-species/full-list-of-threatened-species>; RPDC, 2006. *State of the Environment Tasmania: Introduced Species*. Resource Planning and Development Commission, Hobart. <http://soer.justice.tas.gov.au/2003/bio/4/issue/19/ataglance.php>.

13 Marmion B (2012) Wildlife Conservation (Rare Flora) Notice 2012(2). *Government Gazette*, WA, 6 November, pp. 5305–5311; Hussey BMJ, Keighery GJ, Cousens RD, Dodd J, Lloyd SG (2007) *Western Weeds: a Guide to the Weeds of Western Australia*. Weed Society of Western Australia, Perth.

14 Lindenmayer D (2007) *On Borrowed Time: Australia's Environmental Crisis and What We Must Do About It*. Penguin Books Australia, Melbourne.

15 Birdlife Australia (2008) *State of Australia's Birds*. <http://birdlife.org.au>.

16 Bureau of Meteorology (2013) *Groundwater Dependent Ecosystems Atlas*. Bureau of Meteorology, Canberra. <http://www.bom.

gov.au/water/groundwater/gde/index.shtml>.

17 Great Barrier Reef Marine Park Authority (2009) *Great Barrier Reef Outlook Report 2009*. Great Barrier Reef Marine Park Authority, Townsville. <http://www.gbrmpa.gov.au/__data/assets/pdf_file/0018/3843/OutlookReport_Full.pdf>

18 Collins S (2012) Marine microbiology: evolution on acid. *Nature Geosciences* **5**, 310–311; Lohbeck KT, Riebesell U, Reusch TBH (2012) Adaptive evolution of a key phytoplankton species to ocean acidification. *Nature Geosciences* **5**, 346–351.

19 <http://www.reef.crc.org.au/discover/plantsanimals/cots/>

20 Lindenmayer DB, Gibbons P, Bourke M, Burgman M, Dickman CR *et al.* (2012) Improving biodiversity monitoring. *Austral Ecology* **37**, 285–294.

21 <http://www.environment.gov.au/resource/australias-biodiversity-conservation-strategy-0>

22 Lindenmayer D, Burns E, Thurgate N, Lowe A (2013) *Monitoring Environmental Change.* CSIRO Publishing, Melbourne.

23 <http://www.tern.org.au>

24 Westcott DA, McKeown A, Fletcher CS, Murphy HT (2011) *A Monitoring Methodology for the Grey-headed Flying-fox*, Pteropus poliocephalus. Report to the Australian Government Department of Sustainability, Environment, Water, Population and Communities. <http://www.environment.gov.au/biodiversity/threatened/species/flying-foxes-monitoring-program.html>.

25 Australian Government Department of Sustainability, Environment, Water, Population and Communities (2011) *National Plan for Environmental Information*. <http://www.environment.gov.au/topics/science-and-research/national-plan-environmental-information>.

26 Scholes RJ, Walters M, Turak E, Saarenmaa H, Heip CHR *et al.* (2012) Building a global observing system for biodiversity. *Current Opinions in Environmental Sustainability* **4**, 139–146.

Chapter 4

1 Martin TG, Nally S, Burbidge A, Arnall S, Garnett ST *et al.* (2012) Acting fast helps avoids extinction. *Conservation Letters* **5**, 274–280.

2 Martin TG, Catterall CP, Manning AD, Szabo JK (2012) In *Birds and Habitat: Relationships in Changing Landscapes*. (Ed. RJ Fuller) pp. 453–480. Cambridge University Press, Cambridge.

3 Saunders DA, Arnold GW, Burbidge AA, Hopkins AJM (Eds) (1987) *Nature Conservation: The Role of Remnants of Native Vegetation*. Surrey Beatty, Sydney.

4 Thrall PH, Millsom DA, Jeavons AC, Waayers M, Harvey GR *et al.* (2005) Seed inoculation with effective root-nodule bacteria enhances revegetation success. *Journal of Applied Ecology* **42**, 740–751.

5 Prober SM, Thiele K, Lunt I, Koen TB (2005) Restoring ecological function in temperate grassy woodlands – manipulating soil nutrients, annual exotics and native perennial grasses through carbon supplements and spring burns. *Journal of Applied Ecology* **42**, 1073–1085.

6 Lunt ID, Prober SM, Thiele KR (2010) In *Temperate Woodland Conservation and Management*. (Eds D Lindenmayer, A Bennett, RJ Hobbs) pp. 167–173. CSIRO Publishing, Melbourne.

7 Short J (2009) *The Characteristics and Success of Vertebrate Translocations within Australia: A Progress Report*. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

8 Schwartz M, Martin TG (2013) Translocation of imperiled species under changing climates. *Annals of the New York Academy of Sciences* **1286**, 15–28.

9 McDonald-Madden E, Runge MC, Possingham HP, Martin TG (2011) Optimal timing for managed relocation of species faced with climate change. *Nature Climate Change* **1**, 261–265.

10 Harris S, Arnall S, Byrne M, Coates D, Hayward MW *et al.* (2013) Whose backyard? Some precautions in choosing recipient sites for assisted colonisation of Australian plants and animals. *Ecological Management & Restoration* **14**, 106–111.

11 Aguilar R, Quesada M, Ashworth L, Herrerias-Diego Y, Lobo J (2008) Genetic consequences of habitat fragmentation in plant populations: susceptible signals in plant traits and methodological approaches. *Molecular Ecology* **17**, 5177–5188.

12 Australian Biosecurity Group (2005) *Invasive Weeds, Pests and Diseases: Solutions to Secure Australia*. CRC for Pest Animal Control, CRC for Australian Weed Management and WWF Australia, Canberra.

13 Martin TG (2010) In *Temperate Woodland Conservation and Management*. (Eds D Lindenmayer, AF Bennett, RJ Hobbs) pp. 249–258. CSIRO Publishing, Melbourne.

14 Bradstock RA, Gill AM, Williams RJ (2012) *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World*. CSIRO Publishing, Melbourne.

15 Mantyka-pringle CS, Martin TG, Rhodes JR (2012) Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. *Global Change Biology* **18**, 1239–1252.

16 Stafford Smith M, Horrocks L, Harvey A, Hamilton C (2010) Rethinking adaptation for a 4°C world. *Philosophical Transactions of the Royal Society A* **369**, 196–216. doi:10.1098/rsta.2010.0277.

17 Steffen W, Burbidge AA, Hughes L, Kitching R, Lindenmayer D *et al.* (2009) *Australia's Biodiversity and Climate Change.* Australian Government Department of Climate Change, Canberra.

18 Williams RJ, Bradstock RA, Cary GJ, Enright NJ, Gill AM *et al.* (2010) *Interactions between Climate Change, Fire Regimes and Biodiversity in Australia: A Preliminary Assessment*. Australian Government, Canberra.

19 Gregory R, Long G, Colligan M, Geiger JG, Laser M (2012) When experts disagree (and better science won't help much): using structured deliberations to support endangered species recovery planning. *Journal of Environmental Management* **105**, 30–43.

20 Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems

in the new millennium. *Restoration Ecology* **9**, 239–246.

21 Broadhurst LM, Lowe A, Coates DJ, Cunningham SA, McDonald M *et al.* (2008) Seed supply for broadscale restoration: maximizing evolutionary potential. *Evolutionary Applications* **1**, 587–597.

22 Hobbs RJ, Higgs ES, Hall C (2013) *Novel Ecosystems: Intervening in the New Ecological World Order*. Wiley-Blackwell, Oxford.

23 Miller JR, Hobbs RJ (2007) Habitat restoration – do we know what we're doing? *Restoration Ecology* **15**, 382–390.

24 Carwardine J, O'Connor T, Legge S, Mackey B, Possingham HP, Martin TG (2012) Prioritizing threat management for biodiversity conservation. *Conservation Letters* **5**, 196–204.

25 Gregory R, Failing L, Harstone M, Long G, McDaniels T, Ohlson D (2012) *Structured Decision Making: A Practical Guide to Environmental Management Choices*. Blackwell Publishing, Oxford.

26 Ferrier S, Drielsma M (2010) Synthesis of pattern and process in biodiversity conservation assessment: a flexible whole-landscape modelling framework. *Diversity and Distributions* **16**, 386–402.

27 Mokany K, Harwood TD, Williams KJ, Ferrier S (2012) Dynamic macroecology and the future for biodiversity. *Global Change Biology* **18**, 3149–3159.

28 Levin H, McEwan PJ (2001) *Cost-effectiveness Analysis: Methods and Applications*. 2nd edn. Sage Publications, London.

29 Briggs SV (2009) Priorities and paradigms: directions in threatened species recovery. *Conservation Letters* **2**, 101–108.

30 Joseph JN, Maloney RF, Possingham HP (2009) Optimal allocation of resources among threatened species: a project prioritization protocol. *Conservation Biology* **23**, 328–338.

31 Pannell DJ, Roberts AM, Park G, Alexander J, Curatolo A, Marsh SP (2012) Integrated assessment of public investment in land-use change to protect environmental assets in Australia. *Land Use Policy* **29**, 377–387.

32 Chadès I, McDonald-Madden E, McCarthy M, Wintle B, Linkie M, Possingham HP (2008) When to stop managing or surveying cryptic threatened species. *Proceedings of the National Academy of Sciences* **105**, 13936–13940.

33 Chadès I, Martin TG, Nicol S, Burgman M, Possingham HP, Buckley Y (2011) General rules for managing and surveying networks of pests, diseases and endangered species. *Proceedings of the National Academy of Sciences* **108**, 8323–8328.

34 Webber BL, Scott JK (2012) Rapid global change: implications for defining natives and aliens. *Global Ecology and Biogeography* **21**, 305–311.

35 Bottrill MC, Joseph LN, Carwardine J, Bode M, Cook C *et al.* (2008) Is conservation triage just smart decision making? *Trends in Ecology & Evolution* **23**, 649–654.

Chapter 5

1 Convention on Biological Diversity (2011) *Strategic Plan for Biodiversity 2011–2020 and the Aichi Targets 'Living in Harmony with Nature'*. <http://www.cbd.int/sp/>.

2 Natural Resource Management Ministerial Council (2010) *Australia's Biodiversity Conservation Strategy 2010–2030*. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra. <http://www.environment.gov.au/resource/australias-biodiversity-conservation-strategy-0>.

3 Australian Government Department of Sustainability, Environment, Water Population and Communities (2012) *History of the National Reserve System*. <http://www.environment.gov.au/parks/nrs/about/history.html>.

4 Commonwealth of Australia and each of its States and Territories (2010) *Australia's Strategy for the National Reserve System 2009–2030*. <http://www.environment.gov.au/node/21198>.

5 Australian Government Department of Sustainability, Environment, Water, Population and Communities (2010) *Collaborative Australian Protected Area Database (CAPAD)*. Department of Sustainability, Environment, Water, Population and Communities, Canberra. <http://www.environment.gov.au/topics/land/nrs/science-maps-and-data/capad>.

6 Australian Government Department of Sustainability, Environment, Water Population and Communities (2012) *Commonwealth Marine Reserves Web Page*. <http://www.environment.gov.au/marinereserves/index.html>.

7 Commonwealth of Australia (1997) *Nationally Agreed Criteria for the Establishment of Comprehensive, Adequate and Representative Reserve System for Forests in Australia*. A Report by the Joint ANZECC/MCFFA National Forestry Policy Statement Implementation Subcommittee. <http://www.daff.gov.au/rfa/publications/reserve-system>.

8 <http://www.environment.gov.au/parks/iucn.html>

9 Hill R, Pert PL, Davies J, Walsh F, Robinson CJ, Falco-Mammone F (2013) *Indigenous Land Management in Australia: Extent, Scope Diversity, Barriers and Success Factors.* CSIRO Ecosystem Sciences, Cairns.

10 State of the Environment Committee (2011) *Australia State of the Environment 2011*. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra. <http://www.environment.gov.au/soe/2011/summary/index.html>.

11 Taylor MFJ, Sattler PS, Evans M, Fuller RA, Watson JEM, Possingham HP (2011) What works for threatened species recovery? An empirical evaluation for Australia. *Biodiversity and Conservation* **20**, 767–777.

12 Cochrane P, personal communication. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

13 Taylor MFJ, Sattler PS, Fitzsimons J, Curnow C, Beaver D *et al.* (2011) *Building Nature's Safety Net: the State of Protected Areas for Australia's Ecosystems and Wildlife*. WWF-Australia, Sydney. <http://www.wwf.org.au/?2750/Building-Natures-Safety-Net-2011-The-State-of-Protected-Areas-for-Australias-Ecosystems-and-Wildlife#>.

14 Barr LM, Possingham HP (2013) Are outcomes matching policy commitments

in Australian marine conservation planning? *Marine Policy* **42**, 39–48.

15 Williams KJ, Ferrier S, Rosauer D, Yeates D, Manion G *et al.* (2010) *Harnessing Continent-wide Biodiversity Datasets for Prioritising National Conservation Investment*. CSIRO Ecosystem Sciences, Canberra.

16 <http://www.ala.org.au>

17 Reside AE, VanDerWal J, Phillips B, Shoo LP, Rosauer DF *et al.* (2013) *Climate Change Refugia for Terrestrial Biodiversity: Defining Areas that Promote Species Persistence and Ecosystem Resilience in the Face of Global Climate Change*. National Climate Change Adaptation Research Facility, Gold Coast.

18 Possingham HP, Wilson KA, Andelman SJ, Vynne CH (2006) In *Principles of Conservation Biology* (Eds MJ Groom, GK Meffe, CR Carroll) pp. 509–533. Sinauer Associates, Sunderland, MA.

19 Dunlop M, Hilbert DW, Stafford Smith M, Davies R, James CD *et al.* (2012) *Implications for Policymakers: Climate Change, Biodiversity Conservation and the National Reserve System*. CSIRO Climate Adaptation Flagship, Canberra. <http://www.csiro.au/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/adapt-national-reserve-system.aspx>.

20 Williams P, Faith F, Manne L, Sechrest W, Preston C (2006) Complementarity analysis: mapping the performance of surrogates for biodiversity. *Biological Conservation* **128**, 253–264.

21 Fernandes L, Day JON, Lewis A, Slegers S, Kerrigan B *et al.* (2005) Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. *Conservation Biology* **19**, 1733–1744.

22 Australian Government (2012) *Caring for our Country, Clean Energy Future: Biodiversity Fund Fact Sheet*.

23 Hodgson JA, Thomas CD, Wintle BA, Moilanen A (2009) Climate change, connectivity and conservation decision making: back to basics. *Journal of Applied Ecology* **46**, 964–969.

Chapter 6

1 Trudgen MS, Webber B, Scott JK (2012) Human-mediated introduction of *Livistona* palms into central Australia: conservation and management implications. *Proceedings of the Royal Society B* **279**, 4115–4117; Morton SR, Stafford Smith DM, Dickman CR, Dunkerley DL, Friedel MH *et al.* (2011) A fresh framework for the ecology of arid Australia. *Journal of Arid Environments* **75**, 313–329; Box JA, Duguid A, Read RE, Kimber RG, Knapton A *et al.* (2008) Central Australian waterbodies: the importance of permanence. *Journal of Arid Environments* **72**, 1395–1413; Gott B (2005) Aboriginal fire management in south-eastern Australia: aims and frequency. *Journal of Biogeography* **327**, 1203–1208.

2 State of the Environment Committee (2011) *Australia State of the Environment 2011: Independent Report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities*. Australian Government Department of Sustainability,

Environment, Water, Population and Communities, Canberra.

3 Hill R, Pert PL, Davies J, Robinson CJ, Walsh F, Falco-Mammone F (2013) *Indigenous Land Management in Australia: Extent, Scope, Diversity, Barriers and Success Factors*. Australian Landcare Council Secretariat, CSIRO Ecosystem Sciences, Cairns. <http://www.daff.gov.au/__data/assets/pdf_file/0010/2297116/ilm-report.pdf>.

4 CSIRO (2005) *Aboriginal Wetland Burning in Kakadu*. Video, CSIRO Sustainable Ecosystems, Darwin. <http://www.csiro.au/en/Outcomes/Environment/Bushfires/KakaduWetlandBurning.aspx>.

5 Horton D (1996) Aboriginal Australia map. Australian Institute of Aboriginal and Torres Strait Islander Studies, Canberra.

6 Bradley J, Holmes M, Norman Marrngawi D, Isaac Karrakayn A, Miller Wuwarlu J, Ninganga I (2006) *Yumbulyumbulmantha Ki-Awarawu: All Kinds of Things from Country: Yanyuwa Ethnobiological Classification*. Aboriginal and Torres Strait Islander Studies Unit, University of Queensland, Brisbane.

7 Walsh F, Dobson VP, Douglas J (2013) Anpernirrentye: a framework for enhanced application of indigenous ecological knowledge in natural resource management. *Ecology and Society* **18**, 18. <http://dx.doi.org/10.5751/ES-05501-180318>; *Anpernirrentye: Relationships between Bush Foods, Creation Laws, People, Country and all Things, Illustrated by Three Plants*. DVD, Desert Knowledge CRC and CSIRO, Alice Springs. <http://desertknowledgecrcmedia.com.au/media/anpernirrentye_12_min.html>.

8 Latz P (1995) *Bushfires and Bushtucker: Aboriginal Plant Use in Central Australia*. IAD Press, Alice Springs; Clarke P (2007) *Aboriginal People and their Plants*. Rosenberg Publishing, Melbourne.

9 Gray M, Altman JC, Halasz N (2005) 'The Economic Value of Wild Resources to the Indigenous Community of the Wallis Lake Catchment'. CAEPR Discussion Paper 272/2005. Centre for Aboriginal Economic Policy Research, Australian National University, Canberra; Scelza B, Bird DW, Bliege Bird R (2014) Bush tucker, shop tucker: production, consumption, and diet at an Aboriginal outstation. *Journal of Ecology of Food and Nutrition* **53**, 98–117.

10 Jackson S, Finn M, Featherston P (2012) Aquatic resource use by Indigenous Australians in two tropical river catchments: the Fitzroy River and Daly River. *Human Ecology* **40**, 893–908.

11 Dobson VP (2007) *Arlhe-kenhe Merrethene: Arrernte Traditional Healing*. IAD Press, Alice Springs; Walsh F, Richards D, as told by Hayes-Dobson VP (2013) *Iwepe Irrkenthe Bandage-ke Mpwareme: the Caterpillar Bag is Made into a Bandage*. Video, CSIRO Ecosystem Sciences, Alice Springs.

12 Prober SM, O'Connor MH, Walsh FJ (2011) Australian Aboriginal peoples' seasonal knowledge: a potential basis for shared understanding in environmental management. *Ecology and Society* **16**, 12, <http://www.ecologyandsociety.org/vol16/iss2/art12/>; Woodward E, Jackson S, Finn M, McTaggard PM (2012) Utilising Indigenous seasonal knowledge to understand aquatic resource use and

inform water resource management in northern Australia. *Ecological Management & Restoration* **13**, 58–64. Woodward E, Lindsay B, Kuwarda H, Miljat F, Pirak R, Waliwararra K (2010) *MalakMalak and Matngala Plant Knowledge, Daly River, Northern Territory, Australia.* CSIRO Sustainable Ecosystems, Darwin. <http://www.csiro.au/resources/MalakMalak-Plant-Knowledge-Seasons-Calendar>.

13 Yellow-spotted goanna, *Varanus panoptes*.

14 Paltridge R, Latz P, Pickburn A, Ward M, Ward J, Davey M (2011) Working with Anangu to conserve rare plants in the Anangu Pitjantjatjara Yankunytjatjara lands of South Australia. *Australasian Plant Conservation* **19**, 10–11.

15 Batty D (2012) *Unwelcome Strangers: Weeds on Aboriginal Country*. Video, CSIRO, Alice Springs. <http://www.csiro.au/unwelcomestrangers>; Vaarzon-Morel P (2010) Changes in Aboriginal perceptions of feral camels and of their impacts and management. *Rangeland Journal* **32**, 73–85.

16 Robinson CJ, Smyth D, Whitehead PJ (2005) Bush tucker, bush pets and bush threats: cooperative management of feral animals in Australia's Kakadu National Park. *Conservation Biology* **19**, 1385–1391.

17 Walsh F, Douglas J (2011) No bush foods without people: the essential human dimension to the sustained trade in native plant products from desert Australia. *Rangeland Journal* **33**, 395–416; Gorman J, Whitehead P, Griffiths AD, Petheram L (2008) Production from marginal lands: Indigenous commercial use of wild animals in northern Australia. *International Journal of Sustainable Development and World Ecology* **15**, 240–250.

18 Stephens A (2011) Glow On: Art that Aims to Illuminate. Entertainment section, *Sydney Morning Herald*, 28 September. <http://www.smh.com.au/entertainment/art-and-design/glow-on-art-that-aims-to-illuminate-20110927-1kvco.html>.

19 French A, Long L (2010) *Karlamilyi*. 3 m × 5 m, acrylic on canvas. Martumili Artists, Shire of East Pilbara, Newman.

20 McGregor S, Lawson V, Christophersen P, Kennett R, Boyden J *et al.* (2010) Indigenous wetland burning: conserving natural and cultural resources in Australia's World Heritage-listed Kakadu National Park. *Human Ecology* **38**, 721–729; Yibarbuk D, Whitehead P, Russell-Smith J, Jackson D, Godjuwa C *et al.* (2001) Fire ecology and Aboriginal land management in central Arnhem Land, northern Australia: a tradition of ecosystem management. *Journal of Biogeography* **28**, 325–343; Bliege Bird R, Bird DW, Codding BF, Parker CH, Jones JH (2008) The 'fire stick farming' hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. *Proceedings of the National Academy of Sciences of the United States* **105**, 14796–14801; Hill R, Baird A, Buchanan D, Denman C, Fischer P *et al.* (2004) *Yalanji-Warranga Kaban: Yalanji People of the Rainforest Fire Management Book*. Little Ramsay Press, Cairns.

21 Russell-Smith J, James G, Vigilante T, Lipsett-Moore G, Morrison J, Looker M (2012) Insights into the biodiversity and social benchmarking components of the

northern Australian fire management and carbon abatement programmes. *Ecological Management and Restoration* **13**, 51–57.

22 Moorcroft H, Ignjic E, Cowell S, Goonack J, Mangolomara S *et al.* (2012) Conservation planning in a cross-cultural context: the Wunambal Gaambera Healthy Country Project in the Kimberley, Western Australia. *Ecological Management and Restoration* **13**, 16–25.

Chapter 7

1 Gott B (2012) Indigenous burning and the evolution of ecosystem biodiversity. *Proceedings of the Royal Society of Victoria* **124**, 56–60.

2 Hopper SD (2009) OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. *Plant and Soil* **322**, 49–86.

3 Hermy M, Honnay O, Firbank L, Grashof-Bokdam C, Lawesson JE (1999) An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation. *Biological Conservation* **91**, 9–22.

4 Rackham A (1995) *The History of the Countryside*. Weidenfield & Nicolson, London.

5 Smith JMB (Ed.) (1982) *A History of Australasian Vegetation*. McGraw-Hill, Sydney.

6 Wilson B (Ed.) (1968) *Pasture Improvement in Australia*. Murray, Sydney.

7 Gammage B (2011) *The Biggest Estate on Earth: How Aborigines Made Australia*. Allen & Unwin, Sydney.

8 McIntyre S, Heard KM, Martin TG (2003) The relative importance of cattle grazing in sub-tropical grasslands – does it reduce or enhance plant biodiversity? *Journal of Applied Ecology* **40**, 445–457.

9 McIntyre S, Tongway D (2005) Grassland structure in native pastures: links to soil surface condition. *Ecological Management and Restoration* **6**, 43–50.

10 McIntyre S (2005) Biodiversity attributes of different sward structures in grazed grassland. *Ecological Management and Restoration* **6**, 71–73.

11 Penman TD, Binns DL, Shiels RJ, Allen RM, Kavanagh RP (2008) Changes in understorey plant species richness following logging and prescribed burning in shrubby dry sclerophyll forests of south-eastern Australia. *Austral Ecology* **33**, 197–210.

12 Lindenmayer DB, Franklin JF, Fischer J (2006) General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biological Conservation* **131**, 433–445.

13 Low T (2002) *The New Nature: Winners and Losers in Wild Australia*. Penguin, Melbourne.

14 National Land and Water Resources Audit (2001) *Australian Agriculture Assessment*. National Land and Water Resources Audit, Canberra, ACT.

15 Johnston WH, Garden DL, Rančić A, Koen TB, Dassanayake KB *et al.* (2003) The impact of pasture development and grazing on water-yielding catchments in the Murray-Darling Basin in south-eastern Australia.

Australian Journal of Experimental Agriculture **43**, 817–841.

16 Manning AD, Fischer J, Lindenmayer DB (2006) Scattered trees are keystone structures – implications for conservation. *Biological Conservation* **132**, 311–321.

17 Lindenmayer DB, Hobbs RJ (2004) Fauna conservation in Australian plantation forests – a review. *Biological Conservation* **119**, 151–168.

18 Catterall CP, Piper SD, Bunn SE, Arthur JM (2001) Flora and fauna assemblages vary with local topography in a subtropical eucalypt forest. *Austral Ecology* **26**, 56–69.

19 McIntyre S, McIvor JG, Heard KM (Eds) (2002) *Managing and Conserving Grassy Woodlands*. CSIRO Publishing, Melbourne.

20 Lindenmayer DB, McIntyre S, Fischer J (2003) The landscape continuum of habitat modification and species response: a case study on birds in south-eastern Australia. *Biological Conservation* **110**, 45–53.

21 Chapman SK, Langley JA, Hart SC, Koch GW (2006) Plants actively control nitrogen cycling: uncorking the microbial bottleneck. *New Phytologist* **169**, 27–34.

22 Palm C, Sanchez P, Ahamed S, Awiti A (2007) Soils: a contemporary perspective. *Annual Review of Environment and Resources* **32**, 99–129.

23 House APN, MacLeod ND, Cullen B, Whitbread AM, Brown SD, McIvor JG (2008) Integrating production and natural resource management on mixed farms in eastern Australia: the cost of conservation in agricultural landscapes. *Agricultural Ecosystems and Environment* **127**, 153–165.

24 Hodgson JA, Moilanen A, Wintle BA, Thomas CD (2011) Habitat area, quality and connectivity: striking the balance for efficient conservation. *Journal of Applied Ecology* **48**, 148–152.

25 Doerr VAJ, Barrett T, Doerr ED (2011) Connectivity, dispersal behaviour and conservation under climate change: a response to Hodgson et al. *Journal of Applied Ecology* **48**, 143–147.

26 Pearson SM, Turner MG, Gardner RH, O'Neill RV (1996) An organism-based perspective of habitat fragmentation. In *Biodiversity in Managed Landscapes: Theory and Practice.* (Eds RC Szaro and DW Johnston) pp. 77–95. Oxford University Press, New York.

27 Smith FP, Prober SM, House APN, McIntyre S (2013) Maximizing retention of native biodiversity in Australian agricultural landscapes – the 10:20:40:30 guidelines. *Agriculture, Ecosystems and Environment*, **166**, 35–45.

28 Industry Commission (1998) *A Full Repairing Lease: Inquiry into Ecologically Sustainable Land Management.* Australian Government Publishing Service, Canberra.

29 MacLeod ND, McIvor JG (2006) Reconciling economic and ecological conflicts for sustained management of grazing lands. *Ecological Economics* **56**, 386–401.

30 Whitten S, Carter M, Stoneham G (Eds) (2004) *Market-based Tools for Environmental Management*. Publication 04/142. Rural Industries Research and Development Corporation, Canberra.

Chapter 8

1 Pacione M (2009) *Urban Geography – A Global*

Perspective. Routledge, New York.

2 Australian Bureau of Statistics (2012) <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4102.0Main+Features30April+2013>.

3 Miller JR (2005) Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution* **20**, 430–434.

4 Luck GW, Ricketts TH, Daily GC, Imhoff M (2004) Alleviating spatial conflict between people and biodiversity. *Proceedings of the National Academy of Sciences* **101**, 182–186.

5 Secretariat of the Convention on Biological Diversity (2012) *Cities and Biodiversity Outlook*. Secretariat of the Convention on Biological Diversity, Montreal. <http://www.cbd.int/en/subnational/partners-and-initiatives/cbo>.

6 Mcdonald RI, Kareiva P, Forman RTT (2008) The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation* **141**, 1695–1703.

7 Groves RH, Boden R, Lonsdale WM (2005) *Jumping the Garden Fence: Invasive Garden Plants in Australia and their Environmental and Agricultural Impacts*. WWF-Australia, Sydney. <http://www.wwf.org.au/news_resources/resource_library/?1928/Jumping-the-Garden-Fence-Invasive-garden-plants-in-Australia-and-their-environmental-and-agricultural-impacts>.

8 Williams MSG, McDonnell MJ, Seager UJ (2005) Factors influencing the loss of an endangered ecosystem in an urbanizing landscape: a case study of native grasslands from Melbourne, Australia. *Landscape and Urban Planning* **71**, 35–49.

9 Jokimäki J, Suhonen J (1993) Effects of urbanization on the breeding bird species richness in Finland: a biogeographical comparison. *Ornis Fennica* **70**, 71–77.

10 Hernandez JL, Frankie GW, Thorp RW (2009) Ecology of urban bees: a review of current knowledge and directions for future study. *Cities and the Environment*. <http://digitalcommons.lmu.edu/cate/vol2/iss1/3/>.

11 Parsons H, French K, Major RE (2003) The influence of remnant bushland on the composition of suburban bird assemblages in Australia. *Landscape and Urban Planning* **66**, 43–56.

12 Maklakov AA, Immler S, Gonzalez-Voyer, Ronn J, Kolm N (2011) Brains and the city: big brained passerine birds succeed in urban environments. *Biology Letters* **7**, 730–732.

13 Tratalos J, Fuller RA, Warren PH, Davies RG, Gaston KJ (2007) Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning* **83**, 308–317.

14 Fuller RA, Irvine KN, Devine-Wright P, Warren PH, Gaston KJ (2007) Psychological benefits of green space increase with biodiversity. *Biology Letters* **3**, 390–394.

15 Fuller RA, Gaston KJ (2009) The scaling of green space coverage in European cities. *Biology Letters* **5**, 352–355

16 Shanahan DF, Miller C, Possingham HP, Fuller RA (2011) The influence of patch area and connectivity on avian communities in urban revegetation. *Biological Conservation* **144**, 722–729.

17 Adams R (2009) Transforming Australian cities for a more financially viable and sustainable future: transportation and urban design. *Australian Economic Review* **42**, 209–216.

18 Kenworthy JR (2006) The eco-city: 10 key transport and planning dimensions for sustainable city development. *Environment and Urbanisation* **18**, 67–85.

19 Sushinsky JR, Rhodes JR, Possingham HP, Gill TK, Fuller RA (2013) How should we grow cities to minimize their biodiversity impacts? *Global Change Biology* **19**, 401–410.

20 Lin BB, Fuller RA (2013) Sharing or sparing? How should we grow the world's cities? *Journal of Applied Ecology* **50**, 1161–1168.

21 McDonnell M, Holland K (2008) Biodiversity. In *Transitions: Pathways Towards Sustainable Urban Development in Australia*. (Ed. PW Newton) pp. 253–266. CSIRO Publishing, Melbourne.

22 Young A (2000) *Environmental Change in Australia Since 1788*. Oxford University Press, Melbourne.

23 Almusaed A (2010) *Biophilic and Bioclimatic Architecture.* Springer Verlag, Berlin.

24 Snep RPH, Opdam PFM (2010) Integrating nature values in urban planning and design. In *Urban Ecology*. (Ed. KJ Gaston) pp. 261–286. Cambridge University Press, Cambridge.

25 Global Footprint Network (2013) <http://www.footprintnetwork.org/en/index.php/GFN/>.

26 Environment Protection Authority Victoria (2013) <http://www.epa.vic.gov.au/ecologicalfootprint/default.asp>.

27 Demographia (2013) *Demographia World Urban Areas*. Demographia, Belleville, IL. <http://demographia.com/db-worldua.pdf>.

28 Australian Conservation Foundation (2013) *Consumption Atlas*. Australian Conservation Foundation, Melbourne. <http://www.acfonline.org.au/sites/default/files/resource/index67.swf>.

29 Gregory A, Hall M (2011) Urban water sustainability. In *Water: Science and Solutions for Australia*. (Ed, IP Prosser) pp. 75–88. CSIRO Publishing, Melbourne.

30 Burn S (2011) Future urban water supplies. In *Water: Science and Solutions for Australia*. (Ed. IP Prosser) pp. 89–104. CSIRO Publishing, Melbourne.

31 Australian Conservation Foundation (2010) *Sustainable Cities Index: Ranking Australia's 20 Largest Cities in 2010.* Australian Conservation Foundation, Melbourne. <http://www.acfonline.org.au/sites/default/files/resources/2010_ACF_SCI_Report_Comparative-Table_and_Fact-Sheets.pdf>.

32 Bekessy SA, Gordon A (2007) Nurturing nature in the city. In *Steering Sustainability in an Urbanising World: Policy, Practice and Performance*. (Ed. A Nelson) pp. 227–238. Ashgate, Hampshire.

33 State of the Environment Committee (2011) Built environment. In *Australia State of the Environment 2011: Independent Report to the Australian Government Minister for Sustainability, Environment, Water,*

Population and Communities. Chapter 10. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra. <http://www.environment.gov.au/topics/science-and-research/state-environment-reporting/soe-2011/soe-2011-report/10-built>.

Chapter 9

1 Butler AJ, Rees A, Beesley P, Bax NJ (2010) Marine biodiversity in the Australian region. *PLoS One* **5**, e11831.

2 <http://www.oceantracks.csiro.au/>

3 <http://www.bom.gov.au/oceanography/forecasts/> and <http://www.csiro.au/Outcomes/Oceans/Oceans-and-climate/BLUElink.aspx>

4 <http://imos.org.au/>

5 <http://imos.aodn.org.au/webportal/>

6 Connell SD, Gillanders BM (Eds) (2007) *Marine Ecology*. Oxford University Press, Melbourne.

7 Andrew N (Ed.) (2000) *Under Southern Seas. The Ecology of Australia's Rocky Reefs*. UNSW Press, Sydney, and Kreiger Publishing Company, Malabar, FL.

8 Johnson CR, Banks SC, Barrett NS, Cazassus F, Dunstan PK *et al.* (2011) Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. *Journal of Experimental Marine Biology and Ecology* **400**, 17–32.

9 Last PR, White WT, Gledhill DC, Hobday AJ, Brown R *et al.* (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. *Global Ecology and Biogeography* **20**, 58–72.

10 Poloczanska ES, Hobday AJ, Richardson AJ (2012) *Marine Climate Change in Australia, Impacts and Adaptation Responses: 2012 Report Card*. <http://www.oceanclimatechange.org.au>.

11 Kenchington R, Stocker L, Wood D (2012) *Sustainable Coastal Management and Climate Adaptation: Global Lessons from Regional Approaches in Australia*. CSIRO Publishing, Melbourne.

12 Smith ADM, Fulton EJ, Hobday AJ, Smith DC, Shoulder P (2007) Scientific tools to support the practical implementation of ecosystem-based fisheries management. *Ices Journal of Marine Science* **64**, 633–639.

13 Pomeroy RS, Katon BM, Harkes I (2001) Conditions affecting the success of fisheries co-management: lessons from Asia. *Marine Policy* **25**, 197–208.

14 Pikitch EK, Santora C, Babcock EA, Bakun A, Bonfil R *et al.* (2004) Ecosystem-based fishery management. *Science* **305**, 346–347; Kidd S, Plater A, Frid C (Eds) (2011) *The Ecosystem Approach to Marine Planning and Management*. Earthscan, London.

15 <http://www.csiro.au/Portals/Media/Perfect-food-for-perfect-prawns.aspx>

16 Wild-Allen K, Herzfeld M, Thompson PA, Rosebrock U, Parslow J, Volkman JK (2010) Applied coastal biogeochemical modelling to quantify the environmental impact of fish farm nutrients and inform managers. *Journal of Marine Systems* **81**, 134–147.

17 <http://www.ccsbt.org>

18 Polacheck T (2012) Assessment of IUU fishing for southern bluefin tuna. *Marine Policy* **36**, 1150–1165; Derkley K (2012) On track to rebuild SBT stocks. *Fisheries Research and Development Corporation News* **20**, 16-20; Commission for the Conservation of Southern Bluefin Tuna (2011) *16th Report of the CCSBT Extended Scientific Committee*. Bali, Indonesia. <http://www.ccsbt.org/userfiles/file/docs_english/meetings/meeting_reports/ccsbt_18/report_of_SC16.pdf>.

19 Pielke RA Jr (2007) *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge University Press, New York.

Chapter 10

1 Prosser IP (Ed.) (2011) *Water: Science and Solutions for Australia*. CSIRO Publishing, Melbourne.

2 <http://earthobservatory.nasa.gov/IOTD/view.php?id=3309>

3 McGinness HM, Arthur AD, Reid JRW (2010) Woodland bird declines in the Murray-Darling Basin: are there links with floodplain change? *Rangeland Journal* **32**, 315–327.

4 Pusey BJ, Kennard MJ (2009) *Aquatic Ecosystems in Northern Australia*. Northern Australia Land and Water Taskforce, Canberra.

5 Guzik MT, Austin AD, Cooper SJB, Harvey MS, Humphreys WF *et al.* (2011) Is the Australian subterranean fauna uniquely diverse? *Invertebrate Systematics* **24**, 407–418.

6 Tomlinson M (2011) *Ecological Water Requirements of Groundwater Systems: A Knowledge and Policy Review*. National Water Commission, Canberra.

7 <http://www.bom.gov.au/water/about/publications/document/BOM_GDE_Atlas_info_sheet_WEB.pdf>

8 Chapman AD (2009) *Numbers of Living Species in Australia and the World*. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra.

9 Morgan DL, Gill HS, Potter IC (1998) *Distribution, Identification and Biology of Freshwater Fishes in South-western Australia*. Western Australian Museum, Perth.

10 Murray–Darling Basin Authority (2012) *The Proposed 'Environmentally Sustainable Level of Take' for Surface Water of the Murray–Darling Basin: Method and Outcomes*. Murray–Darling Basin Authority, Canberra.

11 Connell D, Grafton Q (2011) *Basin Futures: Water Reform in the Murray-Darling Basin*. ANU E Press, Canberra.

12 Australian Government (2008) National Heritage List, 2005. No. 105778. Australian Government, Canberra; Maclean K, Bark R, Moggridge B, Jackson S, Pollino C (2012) *Ngemba Water Values and Interests: Ngemba Old Mission Billabong and Brewarrina Aboriginal Fish Traps* (Baiame's Nguunhu). CSIRO Water for a Healthy Country Flagship, Canberra.

13 Natural Resource Management Ministerial Council (2010) *Australia's Biodiversity Conservation Strategy 2010–2030*.

Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

14 Arthington AH, Balcombe SR (2011) Extreme flow variability and the 'boom and bust' ecology of fish in arid-zone floodplain rivers: a case history with implications for environmental flows, conservation and management. *Ecohydrology* **4**, 708–720.

15 Murray-Darling Basin Commission (2004) *Native Fish Strategy for the Murray-Darling Basin 2003–2013*. Murray-Darling Basin Commission, Canberra.

16 Steffen W, Burbidge AA, Hughes L, Kitching R, Lindenmayer D *et al.* (2009) *Australia's Biodiversity and Climate Change: A Strategic Assessment of the Vulnerability of Australia's Biodiversity to Climate Change.* CSIRO Publishing, Melbourne.

17 <http://www.csiro.au/en/Organisation-Structure/Flagships/Water-for-a-Healthy-Country-Flagship/Ecosystems-and-Contaminants/Paika-Lake-and-wetlands-restoration.aspx>

18 Baldwin DS, Colloff MJ, Rees GN, Chariton AA, Watson GO, Court LN, Hartley DM, Morgan MJ, King AJ, Wilson JS, Hodda M, Hardy CM (2013) Impacts of inundation and drought on eukaryote biodiversity in semi-arid floodplain soils. *Molecular Ecology* **22**, 1746–1758.

19 Holland KL, Doody TM, Jolly ID (2011) *Transpiration Water Use and Ecophysiology of Riparian Vegetation at the Bookpurnong Floodplain*. CSIRO Water for a Healthy Country Flagship, Canberra.

20 Australian Government (2012) *National Wildlife Corridors Plan: A Framework for Landscape-scale Conservation*. Australian Government, Canberra.

21 Kingsford RT, Dunn H, Love D, Nevill J, Stein J, Tait J (2005) *Protecting Australia's Rivers, Wetlands and Estuaries of High Conservation Value*. Australian Government Department of Environment and Heritage Australia, Canberra.

22 Zedler JB, Kercher S (2004) Causes and consequences of invasive plants in wetlands: opportunities, opportunists, and outcomes. *Critical Reviews in Plant Sciences* **23**, 431–445.

23 Murray-Darling Basin Authority (2012) *Sustainable Rivers Audit 2: The Ecological Health of Rivers in the Murray-Darling Basin at the End of the Millenium Drought (2008–2010).* Murray-Darling Basin Authority, Canberra.

24 Doody T, Benyon R (2011) Quantifying water savings from willow removal in Australian streams. *Journal of Environmental Management* **92**, 926–935.

25 Murray BR, Zeppel MJB, Hose GC, Eamus D (2008) Groundwater-dependent ecosystems in Australia: it's more than just water for rivers. *Ecological Management & Restoration* **4**, 110–113.

Chapter 11

1 Mudd GM (2009) The sustainability of mining in Australia: key production trends and their environmental implications for the future. In *Research Report No RR5*. Department of Civil Engineering, Monash University and Mineral Policy Institute, Melbourne.

2 Fargher JD, Howard BM, Burnside DG, Andrew MH (2003) The economy of Australian rangelands: myth or mystery? *Rangeland Journal* **25**, 140–156.

3 Australian Government (2006) Indicator: LD-19 Land use and land use change. In *State of the Environment Report, 2006*. <http://www.environment.gov.au/soe/2006/publications/drs/indicator/161/index.html>.

4 Davies P, Mitchell N, Barmuta L (1996) The impact of historical mining operations at Mount Lyell on the water quality and biological health of the King and Queen River catchments, western Tasmania. In *Mount Lyell Remediation Research and Demonstration Program, Supervising Scientist Report 118*. Office of the Supervising Scientist, Canberra.

5 Det Norske Veritas (2011) Assessment of the risk of pollution from marine oil spills in Australian ports and waters. In *Final Report for the Australian Maritime Safety Authority*, PP002916, p. 45. Det Norske Veritas, London.

6 Australian Government (2011) *A Guide to Undertaking Strategic Assessments: Environment Protection and Biodiversity Conservation Act 1999*. Australian Government, Canberra.

7 Great Barrier Reef Marine Park Authority (2009) *Great Barrier Reef Outlook Report*. Great Barrier Reef Marine Park Authority, Townsville.

8 Douvere F, Badman T (2012) *Mission Report: Reactive Monitoring Mission to the Great Barrier Reef (Australia)*. UNESCO and IUCN, Paris. <http://whc.unesco.org/en/documents/117104>.

9 Grant CD (2006) State-and-transition successional model for bauxite mining rehabilitation in the jarrah forest of Western Australia. *Restoration Ecology* **14**, 28–37; Morley S, Grant C, Hobbs R, Cramer V (2004) Long-term impact of prescribed burning on the nutrient status and fuel loads of rehabilitated bauxite mines in Western Australia. *Forest Ecology and Management* **190**, 227–239; Smith MA, Grant CD, Loneragan WA, Koch JM (2004) Fire management implications of fuel loads and vegetation structure in jarrah forest restoration on bauxite mines in Western Australia. *Forest Ecology and Management* **187**, 247–266.

10 Nano CEM, Clarke PJ, Pavey CR (2012) Fire regimes in arid hummock grasslands and *Acacia* shrublands. In *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World* (Eds RA Bradstock, AM Gill, RJ Williams) pp. 195–214. CSIRO Publishing, Melbourne.

11 Cook GD (2012) Fire management and minesite rehabilitation in a frequently burnt tropical savanna. *Austral Ecology* **37**, 686–692.

12 Tongway DJ, Hindley NL (2004) *Landscape Function Analysis: Procedures for Monitoring and Assessing Landscapes with Special Reference to Minesites and Rangelands*. CSIRO Sustainable Ecosystems, Canberra.

13 Tongway D, Hindley N (2003) *Indicators of Ecosystem Rehabilitation Success: Stage Two – Verification of EFA Indicators*. Final Report. In *Report for the Australian Centre for Mining Environmental Research* p. 66. CSIRO Sustainable Ecosystem, Canberra.

14 Andersen AN, Majer JD (2004) Using invertebrates as bioindicators in land management: ants show the way Down-Under. *Frontiers in Ecology and the Environment* **2**, 291–298.

15 Andersen AN (1993) Ants as indicators of restoration success at a uranium mine in tropical Australia. *Restoration Ecology* **1**, 156–167.

16 Andersen AN, Hoffmann BD, Somes J (2003) Ants as indicators of minesite restoration: community recovery at one of eight rehabilitation sites in a central Queensland mine. *Ecological Management and Restoration* **4**, S12–S19.

17 Pickett EJ, Stockwell MP, Bower DS, Garnham JI, Pollard CJ *et al.* (2013) Achieving no net loss in habitat offset of a threatened frog required high offset ratio and intensive monitoring. *Biological Conservation* **157**, 156–162.

18 Environmental Offsets Policy (2012) *Environment Protection and Biodiversity Conservation Act*. Australian Government, Canberra.

19 <http://www.aridrecovery.org.au>

20 Moseby KE, Read JL, Paton DC, Copley P, Hill BM, Crisp HA (2011) Predation determines the outcome of 10 reintroduction attempts in arid South Australia. *Biological Conservation* **144**, 2863–2872.

21 <http://www.ichthysproject.com/environment/environmental-documents>

Chapter 12

1 Data sourced from: Conservation International (2000), cited in Williams J, Read C, Norton A, Dovers S, Burgman M *et al.* (2001) *Biodiversity, Australia State of the Environment Report 2001* (Theme Report). CSIRO Publishing on behalf of Australian Government Department of the Environment and Heritage, Canberra. <http://www.environment.gov.au/node/21579>; Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GVN *et al.* (2001) Terrestrial ecoregions of the world: a new map of life on Earth. *Bioscience* **51**, 933–938; WWF (2013) *Ecoregions: Earth's Most Special Places*. <http://wwf.panda.org/about_our_earth/ecoregions/>.

2 Bastin G, ACRIS Management Commitee (2008) *Rangelands 2008 – Taking the Pulse*. National Land & Water Resources Audit, Canberra.

3 Lindenmayer DB, Gibbons P, Bourke M, Burgman M, Dickman CR *et al.* (2012) Improving biodiversity monitoring. *Austral Ecology* **37**, 285–294.

4 Convention on Biological Diversity (2006) *Global Biodiversity Outlook 2*. Secretariat of the Convention on Biological Diversity, Montreal.

5 Hill R, Halamish E, Gordon IJ, Clark M (2013) The maturation of biodiversity as a global social-ecological issue and implications for future biodiversity science and policy. *Futures* **46**, 41–49.

6 <http://www.cbd.int/sp/targets/>

7 Walker B, Salt D (2006) *Resilience Thinking*. Island Press, Washington, DC.

8 Wilkinson A, Kupers R (2013) Living in the futures: how scenario planning changed corporate planning. *Harvard Business Review*, May.

9 <http://www.csiro.au/national-outlook>

10 State of the Environment Committee (2011) *Australia State of the Environment 2011: Independent Report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities*. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

11 <http://www.riotinto.com/documents/ReportsPublications/RTBidoversitystrategyfinal.pdf>

12 Natural Resource Management Ministerial Council (2009) *Australia's Strategy for the National Reserve System 2009–2030*. Commonwealth of Australia, Canberra.

13 <http://www.fisheries.ubc.ca/publications/comparative-assessment-biodiversity-fisheries-and-aquaculture-53-countries%E2%80%99-exclusive-e>

14 Bax N, Williamson A, Aguero M, Gonzalez E, Geeves W (2003) Marine invasive alien species: a threat to global biodiversity. *Marine Policy* **27**, 313–323.

15 Hill R, Pert PL, Davies J, Robinson CJ, Walsh F, Falco-Mammone F (2013) *Indigenous Land Management in Australia: Extent, Scope, Diversity, Barriers and Success Factors*. CSIRO Ecosystem Sciences, Cairns.

16 Morton SR, Hoegh-Guldberg O, Lindenmayer DB, Harriss Olson M, Hughes L *et al.* (2009) The big ecological questions inhibiting effective environmental management in Australia. *Austral Ecology* **34**, 1–9.

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