Australia
State of the Environment 2016

Land

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Dr Daniel J Metcalfe and Dr Elisabeth N Bui, CSIRO

Acknowledgement of Country

The authors acknowledge the traditional owners of Country throughout Australia,
and their continuing connection to land, sea and community;
and pay respect to them and their cultures,
and to their Elders both past and present.

Australian Government

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Contents

Executive summary

Our soils, landforms and vegetation have co-evolved over millions of years. Their health and condition are inextricably linked. Most importantly, their health and condition fundamentally support our way of life, our wellbeing, and our agriculture and industry. Soil type, depth and condition have an influence on the growth and condition of all types of vegetation. At the same time, changes to vegetation caused by fire, clearing, grazing and harvesting affect the condition of our soils. The *Land* report deals with issues that have direct relevance to the terrestrial environment and its management, and the impacts that changes in that aspect of the environment have on Australians. In this context, it is concerned with soils and vegetation, agriculture and forestry, the resources sector, and urbanisation, and the impacts of these uses of the land. The health and resilience of the land, and the management approaches to it, are covered in other themes. Like other aspects of the environment, the health and resilience of the land are affected by the drivers of population and economic growth.

During the past 5 years, native vegetation has continued to be cleared, bushfire frequencies have increased, and the number of invasive species has also increased. Many agricultural practices have improved, reducing impacts on the environment, but there is room for further improvement. Urban expansion continues, but a slowing in the number of new mining developments has reduced alienation of agricultural land by the resources sector. The area of the conservation estate has increased, as has the area managed by Indigenous Australians. Collaborative engagement in developing national strategies and policies concerning many issues relevant to land management suggests that decisions are being taken at an appropriate scale—for example, national strategies relating to invasive species, and decisions about agricultural development in northern Australia.

The outlook for the Australian land environment will be determined by the choices made to address legacy issues and current pressures, the development of management approaches that are responsive to a changing environment, and the extent to which emerging issues and future pressures are anticipated and prepared for. Climate change is a substantial overarching pressure, but its impacts will largely be felt through existing recognised pressures such as fire, drought and storms. Coordinated planning at a national scale, and at timescales relevant to the existing pressures and their impacts, will be needed to address current management priorities and the demands of a growing population without compromising longer-term requirements to maintain landscape resilience and the provision of vital ecosystem services.

Key findings

Key finding	Explanatory text
Climate change is the most serious threat to land management	The many consequences of climate change, from changing species distributions to shorter agricultural growing seasons and more intense bushfires, pose the greatest medium-term pressure on Australia's land environment.
Ongoing clearing of native vegetation threatens a range of sectors	Native vegetation supports critical ecosystem services, including stabilising soil, housing beneficial pollinators and other animals, and protecting Australia's extraordinary biodiversity. Clearing, including clearing of regrowth, reduces landscape resilience, as well as directly affecting current values.
Bushfire prediction and management are critical	Bushfire is a natural process across most of Australia, but its beneficial effects on the natural landscape can be at cost to life, property and infrastructure. A warming climate is likely to change the frequency and intensity of bushfires. Australia needs to decide how and where to encourage or suppress bushfire.
There is intense and growing competition for land resources	Land is contested by agriculture, the resources industry, urban development and native habitat conservation. Different land uses bring benefits and problems, and Australians need to understand the long-term implications of particular land-use choices, and make decisions based on the best balance of outcomes.
Invasive species pose a major risk to the environment, industry and health	Invasive species—pests, diseases and weeds—threaten agriculture and forestry, native species, natural regeneration and ecosystem resilience. They already have a massive environmental, social and economic impact, and climate change is likely to enable new invasive species to thrive.
Soil and water management is crucial for a productive landscape	Land management practices are improving, particularly in relation to soil management and soil conservation measures. Pesticide and nutrient run-off is also being significantly reduced in some industries, although increasing in others.
Land managed for conservation has expanded	Both the private and public conservation estate has expanded. The area owned and managed by Aboriginal and Torres Strait Islander communities has also increased, although it is often in very remote areas and may not be managed solely for conservation.

Key finding	Explanatory text
Investment in Indigenous land and sea management has increased participation	The critical role that Indigenous Australians can play in managing the land environment has been formally recognised, and land management provides an important means of employment in many remote areas. Confusing and bureaucratic processes still limit engagement of Indigenous people in land management, and short-term funding cycles reduce job security and long-term management planning.
National strategies and policies are ensuring that decisions are made at an appropriate scale	Collaboration between the Australian, state and territory governments in a series of important policy settings regarding management of the land ensures that national decisions are taken at an appropriate scale. Work is needed to ensure that the temporal scale is equally appropriate.

Approach

This report takes a broadly similar approach to the Land chapter in the 2011 state of the environment report (SoE 2011; SoE Committee 2011), and is intended to be an update of that material. A significant addition in 2016 is an attempt to better represent the perspectives of Aboriginal and Torres Strait Islander people. This has been achieved by inviting, where possible, Indigenous project managers to contribute case studies that exemplify particular issues, to ensure that Indigenous contributions to management of land and sea Country are recognised. As well, Indigenous colleagues and the Indigenous Advisory Committee of the Australian Government Department of the Environment and Energy have been provided with an opportunity to review and comment on the report through its development. The articulated views are those of the authors, and any misunderstandings remaining are due to our own errors.

The *Land* report draws on many of the other thematic reports in SoE 2016, particularly *Biodiversity*, *Coasts*, *Heritage* and *Inland water*. Where relevant, we provide a short synthesis and note that particular sections are covered in detail in other reports. For example, in the *Land* report, we typically deal only with surface-water effects; groundwater effects are covered in the *Inland water* report.

The SoE 2011 'Land' chapter reported on soil condition against physiographic regions; we continue to do so to enable comparison with 2011. However, the 2011 assessments were achieved through a series of funded expert-based workshops, which could not be replicated for 2016, so there are issues with comparability for some assessments.

The 2016 *Land* report has been informed by extensive feedback on drafts from Australian, state and territory agency staff, and from broad consultation with academic scientists and Commonwealth Scientific and Industrial Research Organisation (CSIRO) staff. Together with the authors of other thematic reports (*Coasts*, *Biodiversity*), we held an open meeting at the 2015 Ecological Society of Australia conference and circulated a questionnaire to all registered attendees, the responses to which are largely reported in the *Biodiversity* report.

Unmodified savanna woodland vegetation, Newcastle Range, northern Queensland

Photo by Dan Metcalfe, CSIRO

Introduction

Australia defines itself on the basis of its landform, as much as by the biodiversity forged within it and the people whose culture, beliefs and practices have been shaped by it, whether they be members of Indigenous nations who have more than 50,000 years of unbroken contact with the land, or immigrant communities with less than 250 years here. Whatever their history, the land and the values it provides are as critical to the Australian people's sense of place as they are to their ongoing wellbeing—spiritual, emotional and physical. The people have also shaped the land and continue to shape it, with sometimes dramatic consequences. This report considers the state of the land today, the pressures it faces, and the management responses that we are implementing to try to balance our need to use the land and our desire to protect it.

Soil

Soils form at the interface between land, the hydrosphere and the atmosphere. Their formation and placement are the result of complex interactions between differential weathering of primary minerals in rocks, formation of secondary clay minerals, sculpting of landforms, transport and movement of weathered material downhill, accumulation of colluvium and alluvium downslope, leaching and soil horizon formation, and, finally, stabilisation by vegetation.

Our soils, landforms and vegetation have co-evolved over millions of years; their health and condition are inextricably linked. Soil type, depth and condition have an influence on the growth and condition of all types of vegetation. At the same time, changes to vegetation caused by fire, clearing, grazing and harvesting affect the condition of our soils.

If well managed and maintained, the soil system performs many functions or 'ecosystem services'. It:

- stores and filters water
- stores and cycles nutrients
- stores and filters waste products
- stores carbon (it is the largest reservoir of terrestrial carbon)
- hosts plant, animal and microbial biodiversity
- supports agriculture
- provides raw materials (e.g. clay, sand, gravel)
- stores our palaeontological, archaeological and cultural heritage.

However, when not managed properly, soil can decrease these ecosystem services and affect other ecosystem services; for example, clean air can be affected by dust storms, and sediment in water can change river flow patterns, and reduce habitat quality in riparian and coastal marine ecosystems.

Soil is essentially a nonrenewable resource, because it forms and regenerates slowly, over thousands of years, but can degrade rapidly. Some types of degradation, such as nutrient depletion, can be corrected by fertilisation, but this correction may be costly and have negative offsite impacts. Other forms of degradation, such as soil erosion and salinity, are more difficult to remedy. Prevention is the key to avoiding land degradation. However, natural soil constraints on agriculture and the interaction with climate have made it difficult to develop sustainable systems of land use.

Soil is effectively privately managed across much of Australia. However, the impact of healthy, functioning soils on the environment as a whole—such as improving water quality, protecting biodiversity and mitigating excess greenhouse gases—means that soil is also a large public good.

Vegetation

Like the soil that supports it, vegetation is fundamental to ecosystem processes and human survival. Vegetation is vital for:

- producing oxygen for animal and human life
- maintaining air quality by trapping particulates such as dust and pollutants
- maintaining biodiversity, through both plants themselves and the habitat that vegetation provides for other species
- regulating the climate, from the continental scale down to the microscale
- maintaining ecosystem processes—for example, capturing energy through photosynthesis (which supports food chains) and sequestering atmospheric carbon (which mitigates greenhouse gas emissions)
- maintaining hydrological processes involving surface water and groundwater, such as maintaining the porosity of soils and their capacity to retain water
- maintaining soil integrity and stability, including protecting the soil from water and wind erosion
- producing food, fibre, medicines and shelter
- providing vital cultural connection for Indigenous people, triggering seasonal cues for land management activities and harvesting of natural resources.

Australia has a huge and varied flora. More than 85 per cent of it is found nowhere else on Earth, which means that the majority of the natural vegetation that we see is made up of species that evolved in Australia to cope with Australian conditions. The main vegetation types are, in order of area of extent (according to amalgamated major vegetation groups; DoEE 2016), shrublands and grasslands, eucalypt forests and woodlands, open woodlands, other forests and woodlands, and rainforests.

We have also introduced an enormous number of species for our own purposes, particularly for agriculture and recreational gardening. Incredibly, there are now more introduced plant species (more than 41,000) in Australia than there are native species (around 20,000; Department of Agriculture and Food, Western Australia, unpublished data, 2015). The introduced species include agricultural, horticultural and forestry crops, as well as invasive species that pose huge problems for some commercial sectors and the environment.

Australia's native vegetation has been modified to varying degrees by different land uses and management practices throughout the country's human history. Since European settlement, some 13 per cent of native vegetation has been completely converted to other land uses, and a further 62 per cent is subject to varying degrees of disturbance. The cumulative impacts of land uses and management practices on the environmental values of Australia's soils and native vegetation are a central concern for the assessments in this report.

In this report

This report provides an account of the most significant and recent human impacts on our land.

It highlights improvements in land management over some parts of Australia, as well as several adverse trends. Our focus is relatively narrow—primarily on land use, vegetation and soil. In particular, we focus on the land management practices and landscape processes that, in our view, warrant most attention. SoE 2011 is the basis from which we report developments. This report needs to be read in conjunction with other thematic reports in SoE 2016, particularly the *Biodiversity* report; it also shares significant overlaps with the *Inland water* report and *Coasts* report.

The report starts with an introduction to Australia's soils, vegetation and systems of land use. An assessment is then made of the major pressures on soils and vegetation, and the potential threats to the services and products they provide.

This is followed by an analysis of condition and trends in soil and vegetation across the country.

The effectiveness of management for sustaining and protecting our soils and vegetation under different land uses is then considered. The report describes the resilience (ability to cope with change) of the land and the current risks to land function, and concludes with an assessment of the outlook for Australia's land resources.

The larger context for this report is the magnitude of the pressures emerging globally on land use (UNEP 2016). Stated simply, a growing global population requires increases in food production and extraction of the resources needed to build infrastructure, generate energy and maintain a growing standard of living. There are significant constraints to achieving this, including:

- water scarcity
- limited increases in available arable land
- competition between different land uses, such as agriculture, mining, conservation and urban development
- apparent plateaus in yield for major crops, and broader forest and other vegetation management practices
- the need to reduce emissions of greenhouse gases and increase carbon sequestration
- increasing costs of energy and nutrients
- widespread land degradation
- increased waste
- risks from contaminants
- the likely implications of climate change for biodiversity and current land-use systems
- the increasing and cumulative impacts on ecosystem services.

Land: 2011–16 in context

The past 5 years has seen an ongoing relaxation of the effects of the millennium drought and recovery in many areas (the millennium drought in southern Australian lasted from 2000 to 2010, although in some areas it began as early as 1997 and ended as late as 2012). Australian Government 'exceptional circumstances' support ceased in 2012, with $4.5 billion provided since 2001 (Cranston 2012). Water flowed into Kati Thanda (Lake Eyre) in the summer of 2015–16, and 2010–11 was Australia's wettest 2-year period on record. However, dry conditions developed again in Queensland in 2013, and by 2015 some 86.1 per cent of Queensland was drought declared—the highest proportion in the state's history.

The severe tropical cyclone *Yasi* affected large parts of far north Queensland, including large parts of the Wet Tropics of Queensland World Heritage Area, in what has been described as a 1-in-1000-year event (Nott & Jagger 2013); the cyclone caused the death of an estimated 302 million trees (Negrón-Juárez et al. 2014). Dry weather and lightning strikes in early 2016 caused large bushfires in Tasmania, which burned approximately 124,000 hectares, including 19,963 hectares of the Tasmanian Wilderness World Heritage Area (DPC 2016). Concerns have been raised that regeneration of some iconic and threatened communities, including endemic alpine flora and pencil pine stands, is unlikely.

Domestically, Australia's population has grown by about 1.5 million people in 5 years (2010–15) to 23.8 million (ABS 2016a), and there has been a net movement of people from regional areas to cities. This puts greater pressure on Australian agriculture to feed the urban population, while urban sprawl and the resources industry continue to compete for agricultural land. Australia's agricultural industry has continued to amalgamate into fewer, larger enterprises, and the median age of farmers has increased relative to other industries, with fewer under-35s entering the industry. The mining industry has declined, particularly for coal and iron ore, although there has been a slight growth in oil and gas extraction (ABS 2016b). Unconventional gas exploration and extraction have slowed, but expansion of shale gas and coal-seam gas extraction is still highly contested.

The most significant legislative change has been the creation of the new National Landcare Programme to unify the existing Landcare and Caring for our Country programs, and bring core environmental management resourcing into a single scheme. Additionally, reviews of initiatives such as the Australian Pest Animal Strategy, the Australian Weeds Strategy, the Intergovernmental Agreement on Biosecurity and regional forest agreements, and the release of the Australian Government's white papers on agricultural competitiveness and developing northern Australia help to set the scene for the coming years.

Fire-damaged pencil pine (*Athrotaxis cupressoides*), Lake Mackenzie, Tasmania

Photo by Chris Emms, Tasmanian Parks and Wildlife Service, Tasmania

Pressures

affecting the land environment

At a glance

Although a changing climate has shaped the Australian landscape and its vegetation, the current rate of climate change is likely to result in changes in the distribution and composition of vegetation communities. Some communities are likely to disappear, and others will be transformed as different species mix together to form novel communities, in some of which exotic species are likely to play a significant role. Many agricultural and forestry systems are likely to be adversely affected.

Rates of land clearing, although decreasing in many states, are still increasing in some states in response to relaxation of legislative controls. There is recognition that land clearing can affect environmental services, such as control of erosion and maintenance of soil quality, and that habitat fragmentation, which is a typical consequence of land clearing, places increased pressures on the survival of remnant patches of natural vegetation.

Widespread landscape-scale pressures (including invasive species and changed bushfire regimes) continue to threaten land managed for environmental values, conservation and extensive agriculture. Bushfire frequencies are increasing, as are the number of invasive species that are threatening Australian landscapes and industries. Increasing resistance of invasive weeds to herbicides is recognised as a growing problem. Pressures on the land environment associated with grazing—Australia's most extensive land use—have decreased somewhat, with a decrease in the size of the national cattle herd and in the area grazed.

Although better management of many agricultural systems has reduced their impacts on the land environment, a number of issues relating to nutrient and soil management remain. Low-tillage conservation agriculture approaches have been successful, but uptake appears to be declining in some areas. Management of native and plantation forestry faces challenges as the industry ceases to expand, and the delivery of long-term management agreements falls short of expectations.

Urban and peri-urban expansion continues to threaten agricultural land and the viability of some horticultural industries. Legislative approaches are in place in some jurisdictions to help manage these tensions.

Mining developments have slowed in recent years, although the management of former mining sites is an emerging concern. So too is the expansion of unconventional gas extraction, particularly because of concerns about safety, but also because of competition for land with other uses.

Waste production continues to increase, although recycling and re-use are also increasing, in some cases supported by innovative commercial opportunities for recycled products.

Pressures affecting Australia's land environment come from each of the drivers discussed in the *Drivers* report, as well as from the interactions between them. The growing human population and levels of consumption, both domestically and globally, will increase demand for food and fibre. Expanding cities and new infrastructure also continue to affect the environment. Economic growth demands greater extraction of natural resources, although conditions placed on extractors are resulting in increased investment and new technologies for environmental management.

Changed climate regimes and sea level rise associated with global warming are expected to place new pressures on both the natural environment and primary production systems. These pressures and drivers interact—for example, fire regimes are influenced by both climate change, and changing patterns of settlement and land use associated with population and economic growth. Coastal ecosystems will be affected by the interaction between sea level rise and human settlements.

The major pressures affecting Australian soils and vegetation have been identified in previous SoE reports, and in a series of assessments and reviews over the past decade. These pressures are:

- those resulting from climate change, which include increased average temperatures, warmer minimum and maximum temperatures, less predictable rainfall patterns, and more extreme weather events—all of these affect the timing and success of biological processes such as growth, timing of flowering, effective pollination and seed dispersal
- vegetation clearing and associated habitat fragmentation, with consequences for ecosystem services (such as carbon sequestration), soil erosion and biodiversity persistence
- altered fire frequency and intensity, and the extent of both bushfires and managed fires
- changes in land uses and land management practices, including farming and forestry systems, which compete for space with natural systems, affecting ecosystem function and provision of services
- invasive diseases, pest and weeds, which infect, prey on, replace or compete with native species, and reduce agricultural viability
- urban expansion, which competes for land space and affects a range of environmental processes and services; it also requires substantial investment to deal with provisioning and waste services, and infrastructure maintenance
- mining activities, resource exploration and the legacy of abandoned mine sites, and their impacts on landscape, biodiversity and human health
- waste disposal, including landfill and recycling
- water diversions, and changed hydrology and salinity.

Climate change–induced pressures

Our climate is changing. Climate records, such as for rainfall and temperature, continue to be broken—for example, widespread record December temperatures across 4 states in south-eastern Australia in December 2015, Australia's warmest October on record in 2015, Australia's warmest spring on record in 2014, Australia's warmest September on record in 2013, temperature records set in every state and territory in January 2013, record high temperatures in November in 3 states in 2012, and Australia's wettest 2-year period on record in 2010 and 2011 (BoM 2012a,b, 2013a,b, 2014, 2015, 2016).

Although these may be statistically interesting, of much greater significance is the impact that extreme weather conditions have on the land and the wider environment. For millennia, Australia's climate has been characterised by huge seasonal variability (Moros et al. 2009, Stuut et al. 2014). Our landforms are shaped by extremes, and many species are adapted to infrequent and unpredictable boom times. However, the pressures exerted by climate change are likely to change both the distribution and abundance of native and exotic species, and these biological impacts, together with the effects of flood, drought and other weather patterns, will progressively change Australian landscapes. It is worth noting that the effects of climate change are felt most disproportionately by large landholders (through scale) and low socio-economic groups (through lack of capacity to respond)—Indigenous people, especially across the north of Australia, are in both these categories.

We are also increasing our understanding of the impacts of climate change on soils—for example, decreases in soil organic carbon are predicted as a result of increased rainfall variability (Forouzangohar et al. 2016).

Climate change will result in impacts in its own right, but will also exacerbate existing pressures and impacts. In particular, climate change will have implications for the distribution of species and biological communities, water availability, and impacts of natural disasters. In agriculture, declining 'growing-season' rainfall will likely produce less crop biomass to protect soils from erosion. Research and investment are now increasingly focused on adaptation to climate change as well as reducing emissions—for example, adaptive management approaches that anticipate responses and modify them as changes in climate take place with a particular direction and magnitude. These approaches include land-use change or conversion in addition to novel approaches to existing land uses.

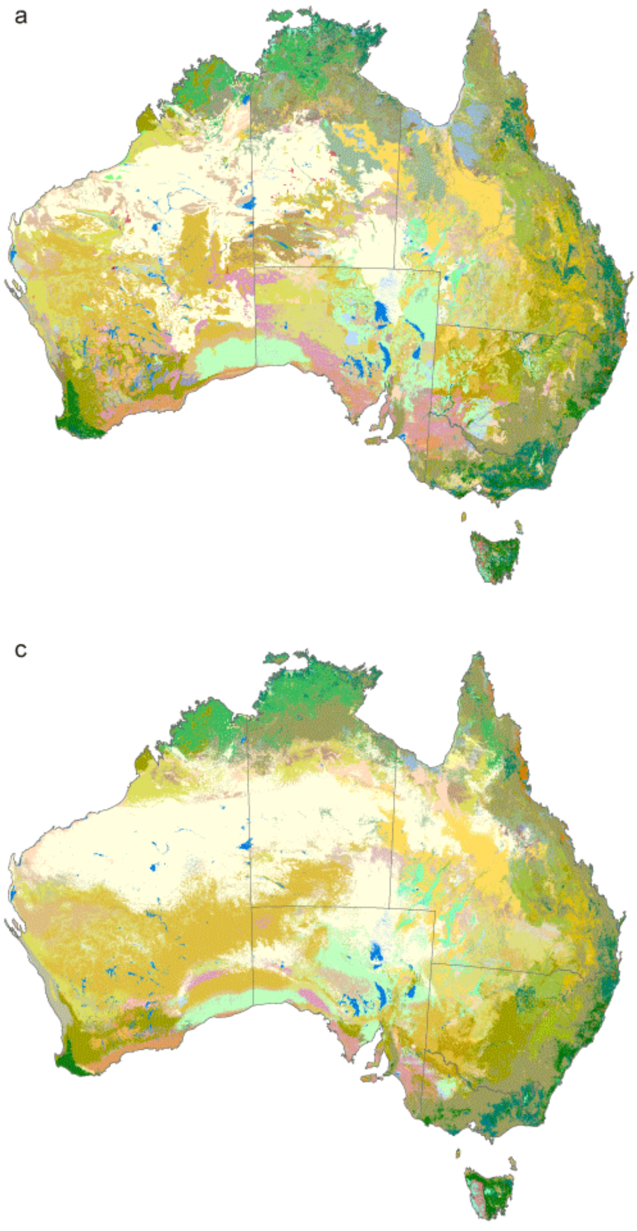
Native vegetation

Australia's native vegetation is extraordinarily adaptable, with a long history of transforming in response to new environmental pressures. Climate change is one such pressure, so change in native vegetation as the climate continues to change may be a positive sign that nature is adjusting. However, as revealed in the AdaptNRM project, a new type of analysis is highlighting that the amount and speed of change could challenge the way we think about and manage our native systems. Although many of Australia's 77 major vegetation subgroups are projected, even under a high–greenhouse gas emissions scenario, to retain somewhat familiar distributions at a broad continental scale, the vegetation at any particular location is often expected to alter in character (Figure LAN1). Furthermore, the environmental conditions projected for some parts of Australia have no present-day analogue, suggesting the potential for the emergence of novel vegetation communities containing combinations of plant species unlike that of any present-day community on the continent (Figure LAN2).

Given the amount and speed of change, we need new ways to approach the management of our native vegetation. The principles we currently use typically focus on preventing change, restoring ecosystems to a pre-European state, or conserving rare and threatened species. New principles are needed that acknowledge change, including loss of some species, and guide us towards more, rather than less, desirable futures for our unique land; this might include recognition of novel communities based on new assemblages of native species. In some cases, non-native species will play a significant role in determining the structure and dynamics of such novel ecosystems, and, in some instances, these roles may be critical.

In addition to direct effects of climate on vegetation, there is also evidence of anomalously long fire-weather seasons, especially from 1996 to 2013 (Clarke et al. 2013, Jolly et al. 2015). These long fire seasons result from periods of benign weather during which fuel loads accumulate, followed by droughts, which permit intense bushfire activity and consequent impacts on vegetation structure, composition and recovery potential.

Understanding the impacts and consequences of climate change provides opportunities for novel or modified land management approaches, including managing vegetation and ecosystem processes for carbon sequestration, and managing land and ecosystems to help build resilience to impacts such as natural disasters.

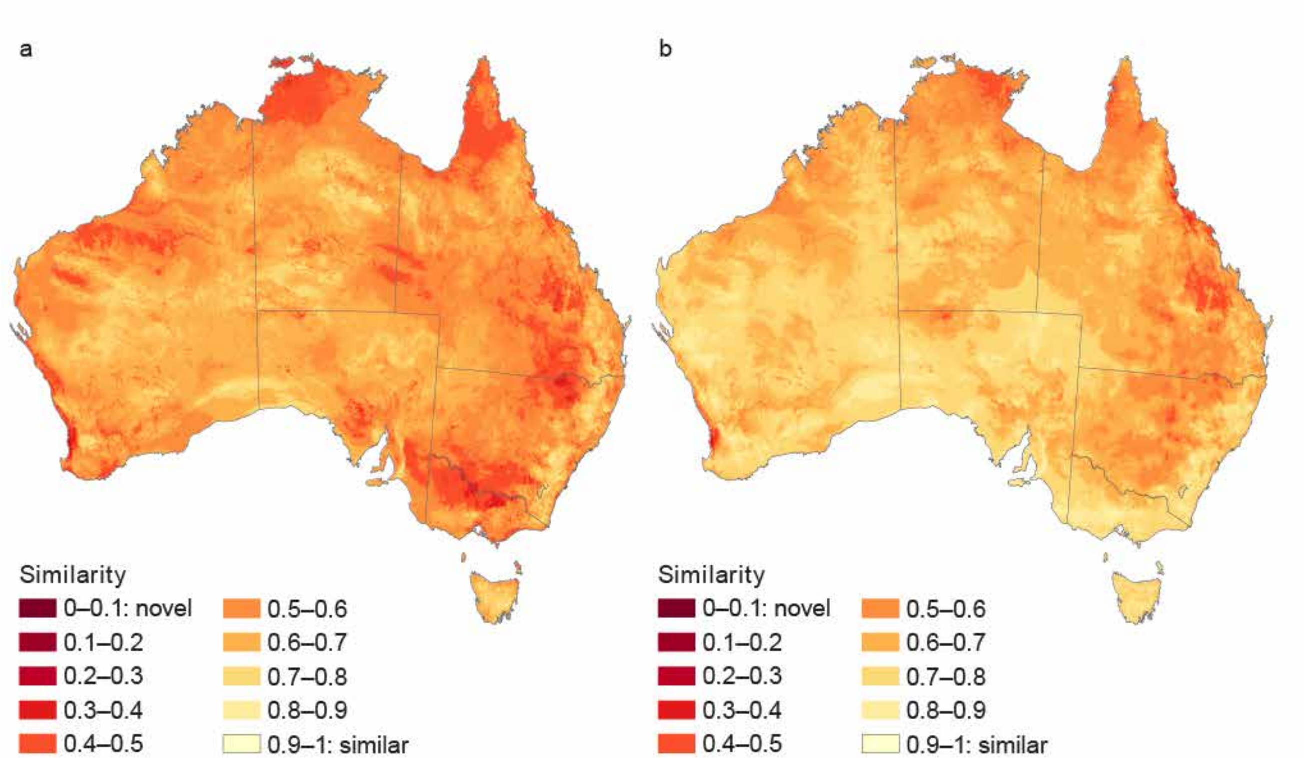


Note: RCP8.5 is 1 of the 4 greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change for its Fifth Assessment Report, which describe the radiative forcing values in the year 2100 relative to pre-industrial values.
Source: Prober et al. (2015), used under CC BY-ND

Figure LAN1 Projected distributions of vegetation types derived by the AdaptNRM project by linking an ecological similarity model, developed for vascular plants, with an existing vegetation map and climate scenarios: (a) observed major vegetation subgroups, from Australia's National Vegetation Information System database; (b) model predictions of subgroups for the baseline period (1990), indicating effectiveness of the modelling, and generalised maps of the projected distribution of subgroups by 2050 for (c) hot Canadian Earth System Model 2, and (d) mild Model for Interdisciplinary Research on Climate 5 climate models, under a high-emissions scenario (RCP8.5)

- Cool temperate rainforest
- Tropical or subtropical rainforest
- *Eucalyptus* tall open forest with a dense broad-leaved understorey (wet sclerophyll)
- *Eucalyptus* open forests with a shrubby understorey
- *Eucalyptus* open forests with a grassy understorey
- Warm temperate rainforest
- Tropical *Eucalyptus* forest and woodlands with a tall annual grassy understorey
- *Eucalyptus* woodlands with a shrubby understorey
- *Eucalyptus* woodlands with a grassy understorey
- *Eucalyptus* woodlands with a tussock grass understorey
- Tropical mixed-species forests and woodlands
- *Callitris* forests and woodlands
- Brigalow (*Acacia harpophylla)* forests and woodlands
- Other *Acacia* forests and woodlands
- *Melaleuca* open forests and woodlands
- Other forests and woodlands
- Boulders/rock wtih algae, lichen or scattered plants, or alpine fjaeldmarks
- *Eucalyptus* low open woodlands with hummock grass
- *Eucalyptus* low open woodlands with tussock grass
- Mulga (*Acacia aneura*) woodlands with tussock grass
- Other *Acacia* tall open shrublands and shrublands
- Arid and semi-arid *Acacia* low open woodlands and shrublands with chenopods
- Arid and semi-arid *Acacia* low open woodlands and shrublands with hummock grass
- Arid and semi-arid *Acacia* low open woodlands and shrublands with tussock grass
- *Acacia* low open woodlands and sparse shrublands with a shrubby understorey
- *Casuarina* and *Allocasuarina* forests and woodlands
- Mallee with hummock grass
- Low closed forest or tall closed shrublands (including *Acacia*, *Melaleuca* and *Banksia*)
- Mallee with a dense shrubby understorey
- Heath
- Saltbush and bluebush shrublands
- Other shrublands
- Hummock grasslands
- Mitchell grass (*Astrebla*) tussock grasslands
- Blue gass (*Dicanthium)* and tall bunch grass (*Chrysopogon*) tussock grasslands
- Temperate tussock grasslands
- Other tussock grasslands
- Wet tussock grassland with herbs, sedges or rushes, herblands or ferns
- Mixed chenopod, samphire +/- forbs
- Mangroves
- Saline or brackish sedgelands or grasslands
- Naturally bare, sand, rock, claypan, mudflat
- Salt lakes and lagoons
- Freshwater, dams, lakes, lagoons or aquatic plants
- Mulga (*Acacia aneura*) open woodlands and sparse shrublands +/- tussock grass
- Sea, estuaries (includes seagrass)
- *Eucalyptus* open woodlands with shrubby understorey
- *Eucalyptus* open woodlands with a grassy understorey
- *Melaleuca* shrublands and open shrublands
- *Banksia* woodlands
- Mulga (*Acacia aneura*) woodlands and shrublands with hummock grass
- *Allocasuarina* woodland and open woodland with hummock grass
- *Eucalyptus* low open woodlands with a shrubby understorey
- *Eucalyptus* tall open forest with a fine-leaved shrubby understorey
- Mallee with an open shrubby understorey
- *Eucalyptus* low open woodlands with a chenopod or samphire understorey
- Lignum shrublands and wetlands
- *Leptospermum* forests
- *Eucalyptus* woodlands with ferns, herbs, sedges, rushes or wet tussock grassland
- *Eucalyptus* tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses
- Mallee with a tussock grass understorey
- Dry rainforest or vine thickets
- Sedgelands, rushs or reeds
- Other grasslands
- *Eucalyptus* woodlands with chenopod or samphire understorey
- Open mallee woodlands and sparse mallee shrublands with an open hummock grass understorey
- Open mallee woodlands and sparse mallee shrublands with an open tussock grass understorey
- Open mallee woodlands and sparse mallee shrublands with an open shrubby understorey
- Open mallee woodlands and sparse mallee shrublands with an open dense shrubby understorey
- *Callitris* open woodlands
- *Casuarina* and *Allocasuarina* open woodlands with a tussock grass understorey
- *Casuarina* and *Allocasuarina* open woodlands with a hammock grass understorey
- *Casuarina* and *Allocasuarina* open woodlands with a chenopod shrub understorey
- *Casuarina* and *Allocasuarina* open woodlands with a shrubby understorey
- *Melaleuca* open woodlands
- Other open woodlands
- Other sparse shrublands and sparse heathlands
- Unclassified forest
- Unclassified native vegetation
- Unknown/no data

Figure LAN1 (continued)



Note: RCP8.5 is 1 of the 4 greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change for its Fifth Assessment Report, which describe the radiative forcing values in the year 2100 relative to pre-industrial values.
Source: Williams et al. (2014), used under CC BY-ND

Figure LAN2 **Degree to which environmental conditions are projected to become sufficiently novel by 2050 to potentially result in the emergence of vegetation communities containing combinations of plant species highly dissimilar from any present-day community on the continent, for (a) hot Canadian Earth System Model 2, and (b) mild Model for Interdisciplinary Research on Climate 5 climate models, under a high-emissions scenario (RCP8.5)**

Diseases, pests and weeds

Changes in climate will affect the viability, distribution and occurrence of diseases, pests and weeds in different ways. Many naturalised introduced plant species appear likely to become less of a threat as the habitat that they currently occupy becomes less suitable (Roger et al. 2015), but the large pool of naturalised species means that currently less invasive species may be poised to take over (see Box LAN1). Pests and diseases are likely to extend into new habitats that are currently unavailable to them (Roger et al. 2015), while native species may extend their range or their influence in concert with changing environmental effects (see Box LAN2).

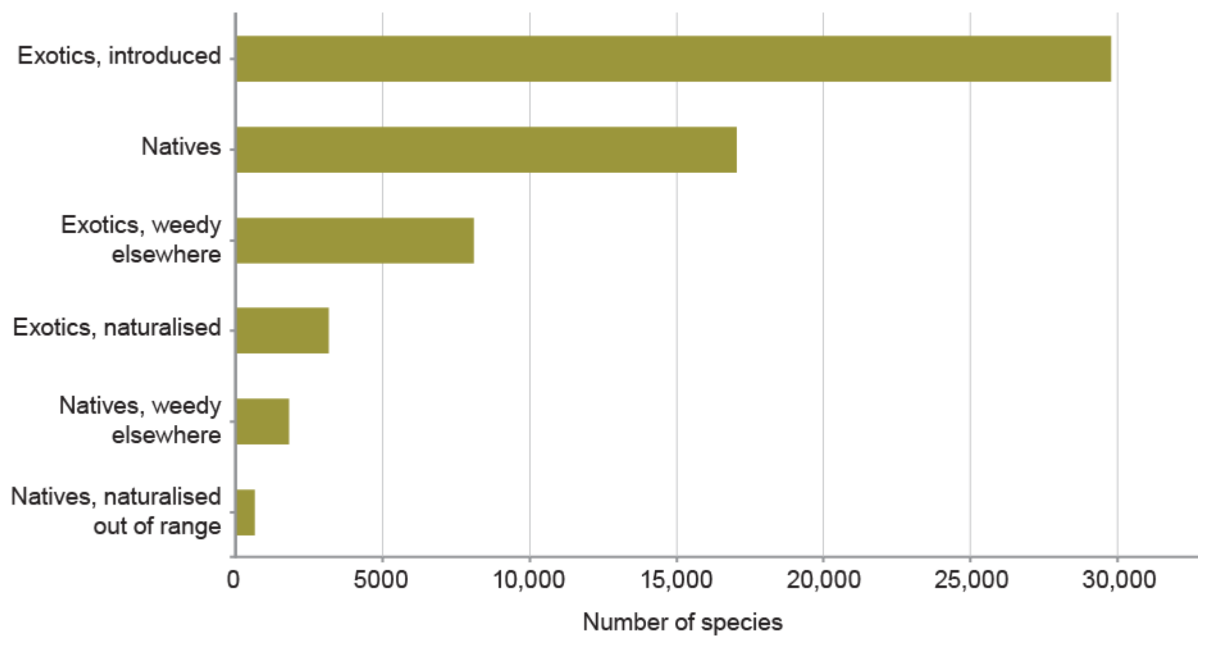
The National Environmental Biosecurity Response Agreement (NEBRA) was signed by the Australian Government and all state and territory governments in January 2012. NEBRA operates in tandem with the Emergency Animal Disease Response Agreement (EADRA) and the Emergency Plant Pest Response Deed (EPPRD) in providing national arrangements for eradication responses to pest or disease incursions. While the EADRA and the EPPRD provide arrangements for responding to pests and diseases that affect agricultural industries, NEBRA facilitates responses to pest and diseases incursions where eradication primarily benefits the community. All 3 of the emergency response deeds, depending on the exotic pest or disease, may cover an incursion that could affect the environment or biodiversity.

Box LAN1 Scale of plant introductions to Australia

Since colonisation of Australia by Europeans, more than 41,000 plant species have been introduced into Australia, and 3175 of these have since become naturalised (Department of Agriculture and Food, Western Australia [DAFWA], unpublished data, 2015; Figure LAN3).

Australia has at least 20,000 native plant species (Chapman 2009). Because more than half of these have been cultivated (DAFWA, unpublished data, 2015), many natives have become weedy outside their native range.

With more than 60,000 plant species in Australia (DAFWA, unpublished data, 2015), there are now 2 pools of potential weeds that could pose new problems in the future: introduced exotics (8108 species) and Australian natives that are known to be weedy overseas (1824 species). Many of these almost 10,000 species (DAFWA, unpublished data, 2015) may never become weedy in Australia, but for some it is just a matter of time and circumstance.



Source: © Rod Randall, Department of Agriculture and Food, Western Australia, all rights reserved

Figure LAN3 Native and exotic plants in Australia

Box LAN2 Climate-related dieback in temperate woodlands

Forest boundaries move back and forth across the landscape in response to local climate variation, disturbance events, endemic insect outbreaks and other ‘natural’ events. Dieback, a gradual decline in tree health that often leads to premature death, is commonly associated with natural forest boundary retreats. With time, forests usually recover from these natural dieback events. However, dieback has been identified as an increasing problem beyond natural variation throughout Australia and the world.

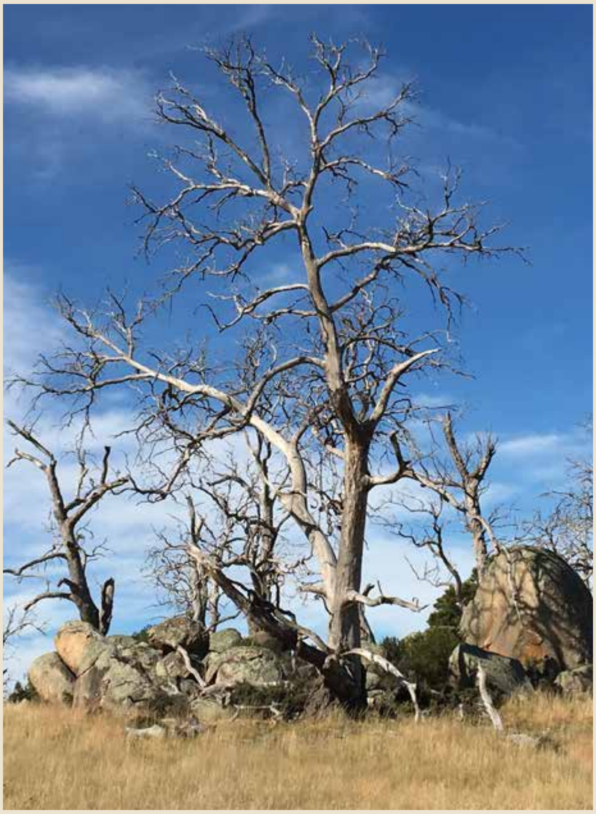
Fossil evidence shows that, over the centuries, trees on the hilltops and ridgelines in the Monaro region of south-eastern New South Wales have moved onto the grassy plains in some centuries and retreated in others. During the past decade, however, the dominant ribbon gums (*Eucalyptus viminalis*) have suffered widespread decline, and almost all are now dead or suffering severe dieback symptoms. This dieback covers an area of around 2000 square kilometres between Bredbo, Numeralla, Nimmitabel and Jindabyne, with the most severely affected areas in a central region around Berridale. If all these trees die, there will be no remnant population to enable this important tree species to return to the area should conditions improve.

In the 1970s and 1980s, ‘rural dieback’ in the New England area of New South Wales was attributed to agricultural practices such as grazing, fertilisation and understorey clearing, which upset the balance of insects and their predators. The resulting insect population explosion led to repeated defoliation, which, over several years, exhausts the trees’ ability to recover. Other cases have been associated with a range of complex factors such as changed fire regimes, pollutants and fungal pathogens.

In the case of the Monaro dieback, the ultimate cause of death seems to be an infestation of (native) eucalyptus weevils (*Gonipterus* sp.), which have been observed in large numbers on the few surviving trees. However, the underlying cause of this outbreak remains unclear. In a recent study (Ross & Brack 2015), ribbon gums appeared to be uniformly dead or showing signs of severe dieback regardless of their local environment. Areas that had been fenced off from grazing and with no other major disturbance might have been expected to be more resilient to dieback, but were as badly affected as those in paddocks that had been fertilised or grazed. Similarly, absence or presence of recent fire made no difference to the trees’ health.

Climatic factors may have played a role, given that the onset of the dieback coincided with the millennium drought. The Monaro region has a harsh climate, with extremes of temperature and low, unpredictable rainfall due to the rain shadow of the Snowy Mountains. Ribbon gums normally grow in wetter areas, and the Monaro is at the edge of their climatic range, so the millennium drought and ongoing climate change may have pushed the trees beyond a critical threshold.

With no evidence of recovery, it is likely that *E. viminalis* will disappear from the Monaro entirely, resulting in dramatic changes to the landscape and loss of biodiversity. Strategies for rehabilitation may include introducing species from more arid environments to accelerate adaptation to the changing climate.



Dead ribbon gums (*Eucalyptus viminalis*) in the Monaro region, New South Wales

Photo by Kylie Evans, Biotext

Source: Cris Brack and Catherine Ross, Australian National University

Agricultural and forestry production systems

The impacts of climate change on forestry and agricultural production will vary by crop, location and season. Under all climate change scenarios, seasonality is predicted to become more pronounced—for example, longer dry seasons, wetter wet seasons and hotter summers—and the intensity and/or frequency of extreme events are likely to continue to increase (Lewis & King 2015, Pepler et al. 2016).

New land uses such as carbon plantings, environmental plantings, and biofuels and bioenergy will need to be considered along with agricultural productivity and water resource maintenance, and potentially better governance approaches will be required to manage these uses (Bryan et al. 2016). Modelling suggests that market incentives that effectively price environmental services are needed, to ensure that efficient land-use arrangements are selected as the climate and society's preferences change (Bryan et al. 2015). Climate change impacts will also mean that the productivity of some regions will change (some will become more productive, and some will become marginal or less productive), and some crops and varieties may need to change (Kelly 2014). However, although increased productivity is expected to maintain the level of agricultural production, despite the reduction in area brought about by new land uses and further urban development, this is predicated on significant investment in productivity improvements. The current evidence of decline in investment is therefore disturbing (Grundy et al. 2016).

Atmospheric carbon dioxide levels will increase, accompanied by increased temperatures and less predictable rainfall patterns (DoEE n.d.). Reduced availability of water is to some extent offset by elevated carbon dioxide levels, which can increase transpiration efficiency—that is, plants are able to absorb sufficient carbon dioxide from the atmosphere more quickly when it is at higher concentrations, so they will lose less water during the process. As well, higher carbon dioxide levels also increase the efficiency of use of sunlight and consequently overall growth rates (Lobell et al. 2015). However, the increase in temperature and drought frequency will have detrimental effects on plant growth patterns, grain production and ripening. Drought and the impact of heat stress are likely to remain the key challenge for farmers for the next 50 years (Lobell et al. 2015).

Pinkard (2014) suggests that plantation productivity has already been detrimentally affected during the past 40 years by climate change. Direct impacts of climate change on productivity are changes in the incidence and severity of droughts, heatwaves and extreme weather events; increasing temperatures; and reduced rainfall. Indirect impacts are increased pest activity and increased fire hazard.

Increasing climate variability is also a major challenge for horticulture because growers depend on a predictable climate for water availability and seasonal temperature (seasonal changes trigger plant growth responses, so unpredictable changes can pose a threat to production; Horticulture Australia 2006). Climate change also provides opportunities for new industries, such as carbon farming for sequestration, as well as challenges for changed management to avoid greenhouse gas emissions. Opportunities to reduce emissions and potentially achieve zero carbon emissions from agriculture through adopting existing management approaches and technology are outlined in a discussion paper by Beyond Zero Emissions, and the University of Melbourne's Melbourne Energy Institute and Melbourne Sustainable Society Institute (Longmire et al. 2014).

Assessment summary 1

Climate change pressures affecting the land environment

Component	Summary	Assessment grade (Very high impact / High impact / Low impact / Very low impact)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Climate change–induced impacts on native vegetation	Models suggest that substantial modifications to some communities are likely, and beyond our ability to prevent. Recent increases in fire-weather seasons suggest that climate change will also result in increasing incidence of community-changing wildfires	High impact ↙	◕	◕	◆
Climate change–induced impacts on diseases, pests and weeds	Some currently significant diseases, pests and weeds are likely to become less of a threat, but a huge pool of 'sleeper weeds' (plants that may appear benign for many years but suddenly spread rapidly following a triggering event such as fire or flooding), and naturalised animals and diseases are likely to pose an increased risk	High impact ↙	◕	◕	◆
Climate change–induced impacts on agricultural and forestry production systems	Increased climate variability is likely to have the greatest impacts, particularly through drought. Some cropping regions will have to move	High impact —	◕	◕	◇

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Grades

- **Very low impact:** There are few or negligible impacts on land environmental values
- **Low impact:** Expected impacts are not widespread and may affect only a small number of land environmental values
- **High impact:** Expected impacts are widespread and may irreversibly affect land environmental values
- **Very high impact:** Expected impacts are widespread and will irreversibly affect land environmental values

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Regional and landscape-scale pressures

Bushfire

Bushfires (wildfires) are uncontrolled fire in the landscape. These particularly affect natural or seminatural vegetation, and have significant positive and negative effects on landscape and ecosystem processes. Because Australia is a continent where bushfire is a common and, indeed, vital contributor to natural processes, and because many vegetation types encourage bushfires—with highly flammable foliage, litter and oils—bushfire can be beneficial to some species and ecological communities. For example, heat and smoke are required to stimulate germination in some species, high temperatures cause seed release in other species, and bushfires maintain habitat heterogeneity by leaving a mosaic of burnt and unburnt patches. On the other hand, bushfires that burn too hot, too frequently, or over too large an area may kill off regeneration, reduce landscape diversity, change soil characteristics, increase erosion and reduce water quality.

Australian weekly bushfire frequencies increased by 40 per cent during the period 2007–13 (Dutta et al. 2016), and some sites experienced fire more than 20 times between 1988 and 2015 (Russell-Smith 2016; Figure LAN4). Because weekly bushfire frequencies are strongly dependent on weekly trends in soil moisture, solar irradiation, fuel dryness and wind speed, these data indicate a major climatic shift. Such an increase in frequency is likely to be deleterious to some ecological communities, even those that are fire dependent (Murphy et al. 2010). There is increased recognition of the cost of uncontrolled bushfires, not just in human life and property, but also in ecosystem function and environmental services (Stephenson et al. 2013).

In response to increased understanding of the impacts of altered fire regimes, research and management actions are increasingly aimed at reintroducing more 'natural' fire regimes, analogous to historical Indigenous fire management practices or the patchiness of naturally occurring wildfires triggered by lightning strikes.

Land clearing

Land clearing represents a fundamental pressure on the land environment, causing the loss and fragmentation of native vegetation. Depending on subsequent management, land clearing can also lead to a variety of impacts on soils, including erosion and loss of nutrients. In addition to the negative impact on native vegetation and soil quality, historical land clearing and other colonial activity disrupted or destroyed traditional Indigenous land management practices.

Loss of native vegetation

Extensive historical clearing resulting in fragmentation continues to exert pressures on the land environment. Clearing rates have decreased over time, largely due to the reduced availability of forested land to clear over time (Figure LAN5). Approximately 44 per cent of Australian forests and woodlands have been cleared since European settlement; 39 per cent was cleared before 1972, although the proportion of any single community lost ranges from complete clearance to an increase in extent due to replacement of other vegetation communities (Figure LAN6). The 3 most heavily cleared communities (mallee with a tussock grass understorey, brigalow, and temperate tussock grasslands) together previously covered more than 170,000 square kilometres of Australia, and each has less than 20 per cent of its original extent remaining (Tulloch et al. 2015).

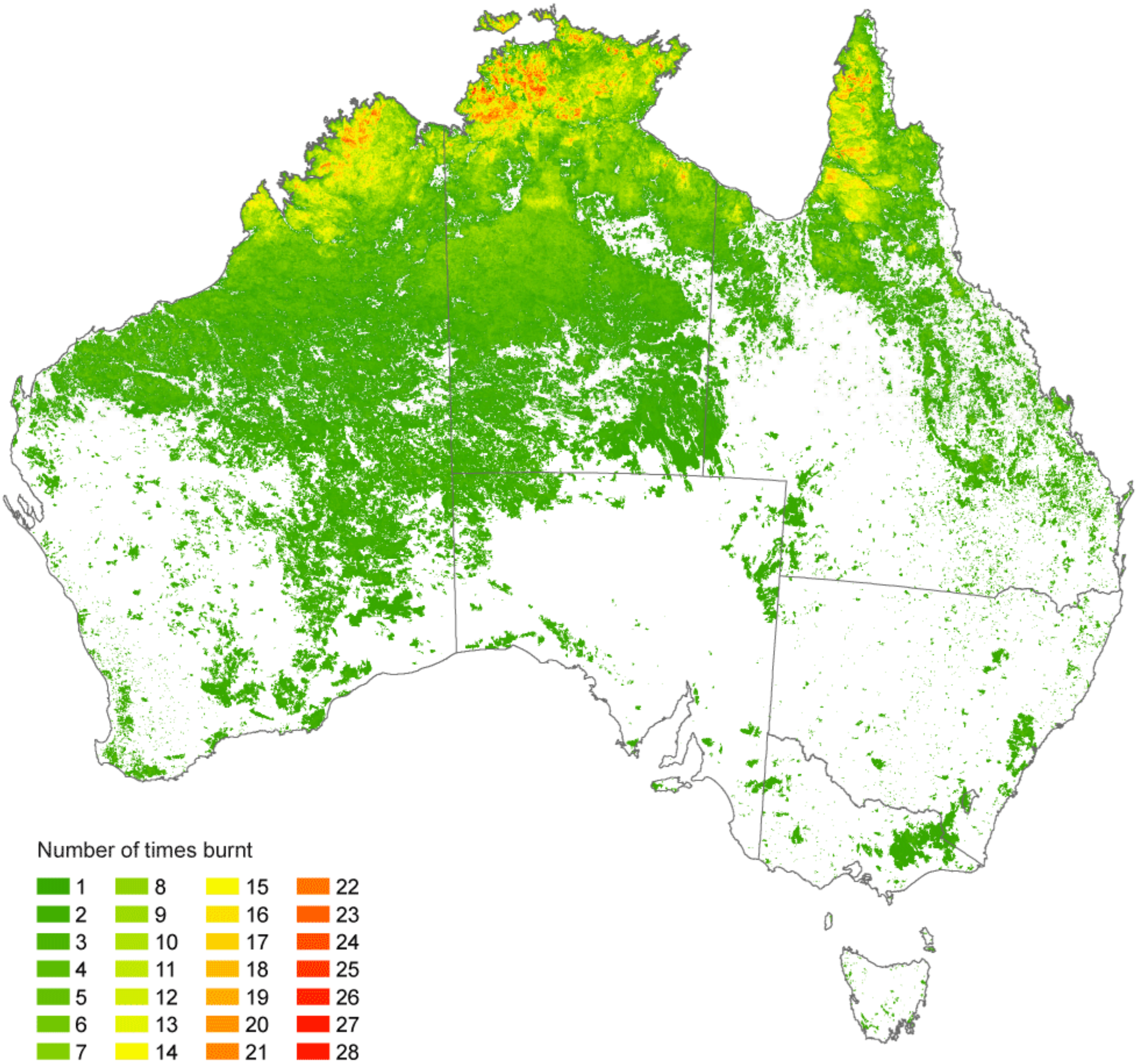
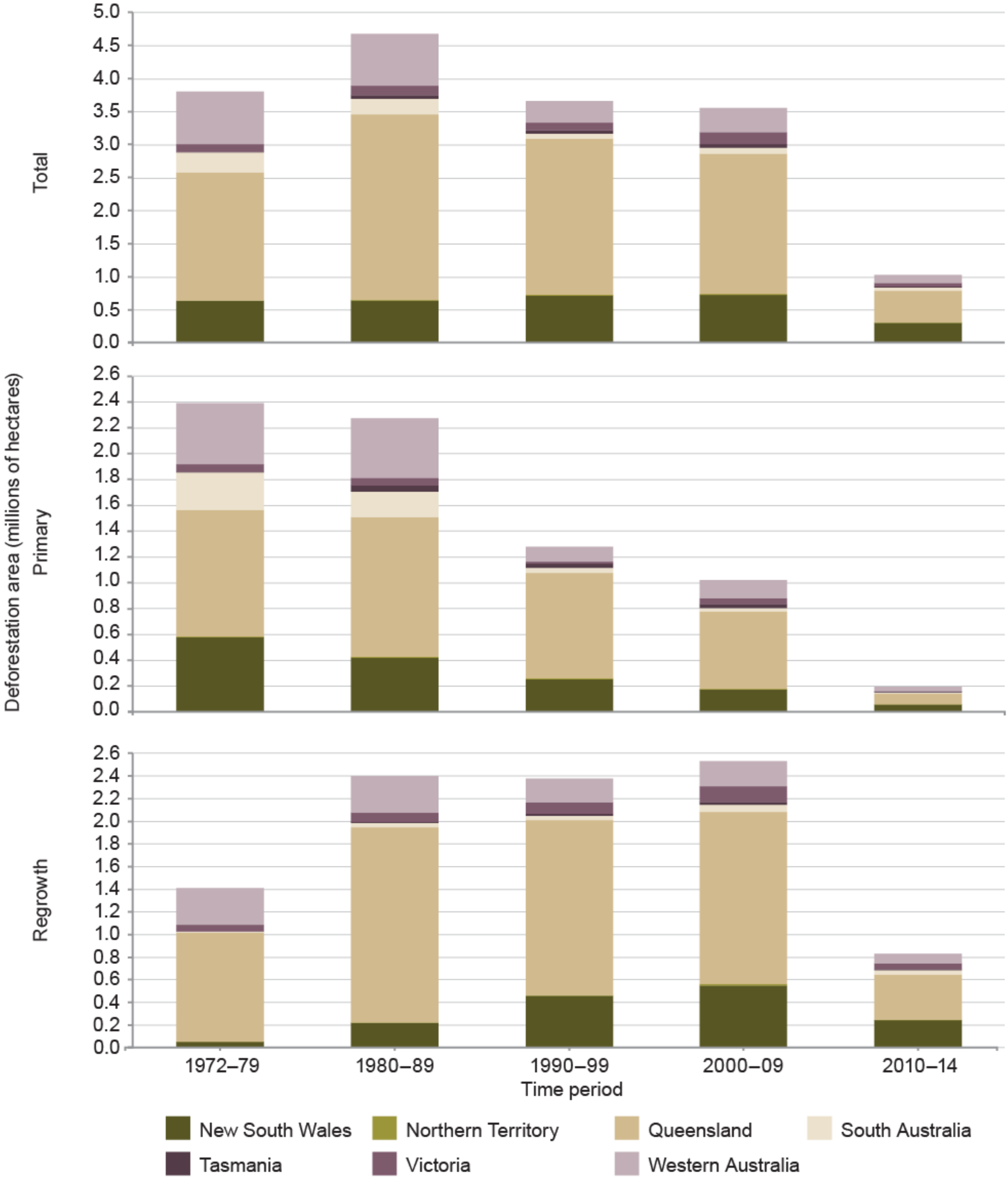
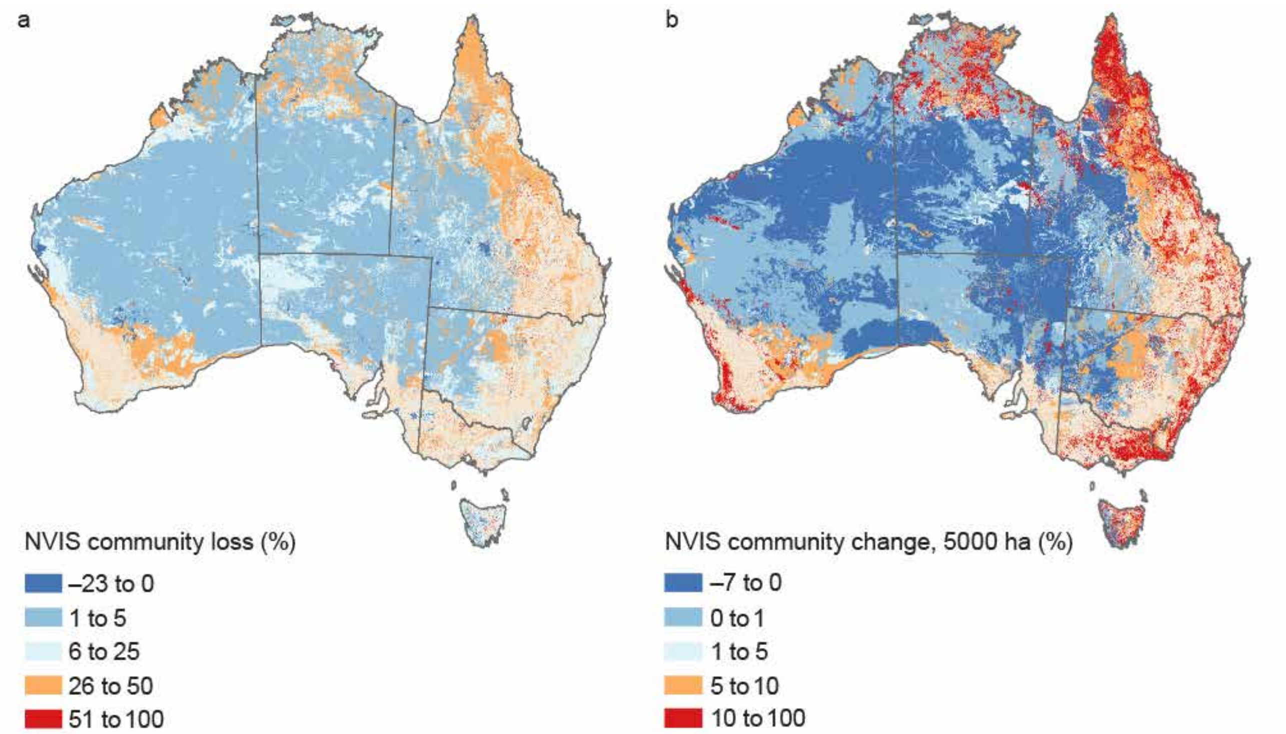


Figure LAN4 National fire return frequency for Australia, 1988–2015



Note: Data for the Australian Capital Territory are not included in these estimates because the deforestation there is small relative to other jurisdictions.
Source: Reproduced from Evans (2016), with permission from CSIRO Publishing

Figure LAN5 Amount of deforestation (total, primary, regrowth) per decade for each state and territory, 1972–2014

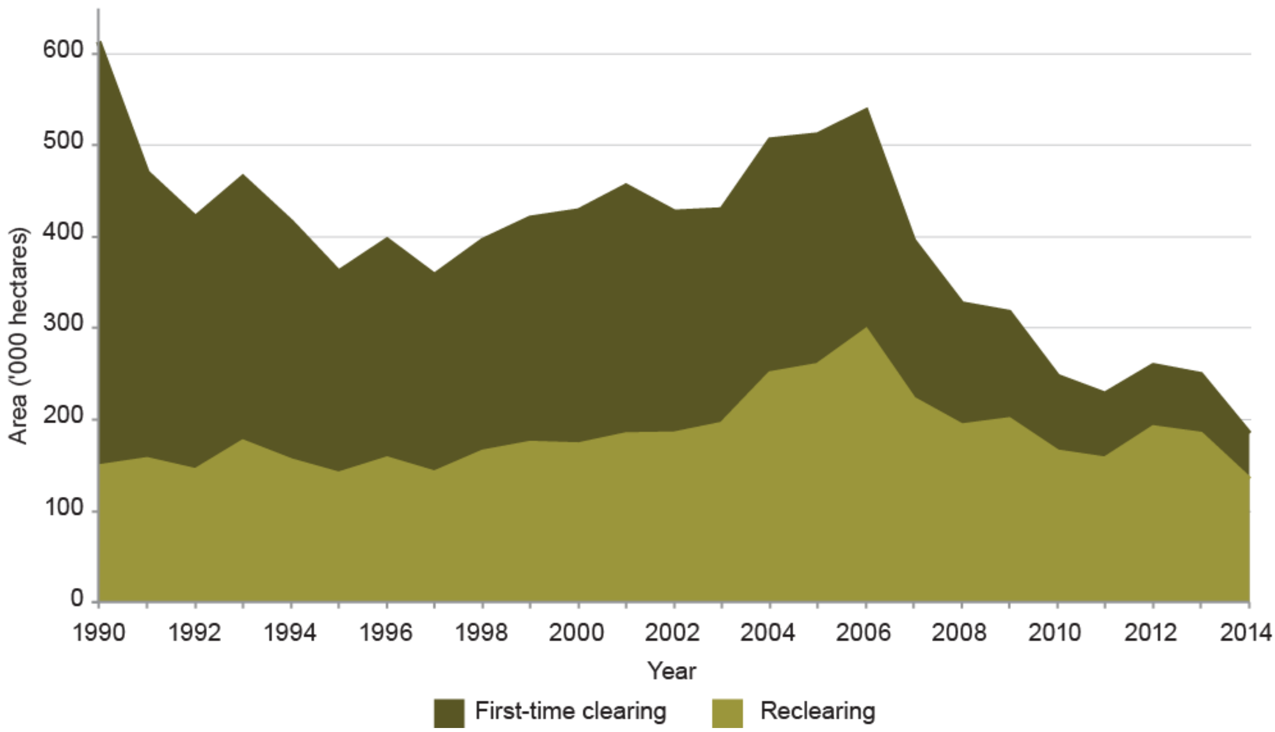


Note: Each National Vegetation Information System (NVIS) vegetation community is colour coded by (a) total loss of extent and (b) a fragmentation measure (change in proportion made up of patches of <5000 hectares).
Source: Adapted from Tulloch et al. (2015), used under CC BY-ND-NC 4.0

Figure LAN6 Continental pattern of Australia's forest cover change

The Australian Government Department of the Environment and Energy uses detailed satellite data to track and report, on a national scale and by state and territory, the greenhouse gas emissions from land clearing and regrowth of vegetation as part of Australia's national greenhouse gas accounting obligations. Annual forest clearing activity and associated emissions from 1989 are analysed and reported each year as part of the Australian Government's National Inventory Report, in accordance with the United Nations Framework Convention on Climate Change and its Kyoto Protocol (Figure LAN7). Note that Figures LAN5 and LAN7 essentially use the same dataset produced by the department for the national inventory of greenhouse gas accounts. However, the estimates shown in these figures differ in how they define primary clearing (first clear) and regrowth clearing (reclear). The Full Carbon Accounting Model (FullCAM; Figure LAN7) applies a stricter test of reclearing. In FullCAM, reclearing includes more than one clearing and also first clearing of young forests that have grown on lands that were cleared before 1972.

The Australian Government Department of the Environment and Energy estimates a net loss of forest, from human-induced conversion of forest to other land uses and gains from human-induced revegetation, of 149,000 hectares in 2014. This is similar to the net loss recorded in 2009 (153,000 hectares), but higher than in 2011, when there was an estimated net gain of forest cover of 65,000 hectares. For woody vegetation that does not meet the forest thresholds, there was a net gain of 330,000 hectares in 2014, down from net gains estimated for 2009 (1,618,000 hectares) and 2011 (1,637,000 hectares). Drivers of change in woody cover are complex; they reflect a mix of factors, including climate signals, economic conditions, and changes in management practices and land management regulations.



Source: Based on data from the Australian Greenhouse Emissions Information System—Land Use, Land Use Change and Forestry Activity Table 1990–2014 (August 2016)

Figure LAN7 First-time forest conversion and reclearing in Australia, 1990–2014

Each state and territory has its own native vegetation legislation, and associated issues relating to agriculture and land-clearing rates. In Queensland, clearing has increased since 2011. Following the introduction of a ban on broadscale clearing that came into effect in 2006, and the extension of clearing controls to high-value regrowth in 2009, land clearing fell to a historical low of 78,378 hectares in 2009–10. High-value regrowth refers to nonremnant vegetation that was cleared more than 20 years earlier. Major reforms to the *Vegetation Management Act 1999* were introduced in 2013 to allow landholders to clear vegetation not cleared since 31 December 1989 on land that is suitable for economically viable agricultural development. This change recognises that restrictions on how native vegetation could be managed were having an impact on agricultural productivity, a topic revisited in the recent *Agricultural competitiveness white paper* (Australian Government 2016). By 2013–14, clearing had increased to 296,324 hectares. This compares with the average annual rate of land clearing before the 2006 ban of 448,000 hectares per year. A recent report by the World Wildlife Fund (Taylor 2015) on clearing rates in Queensland found that:

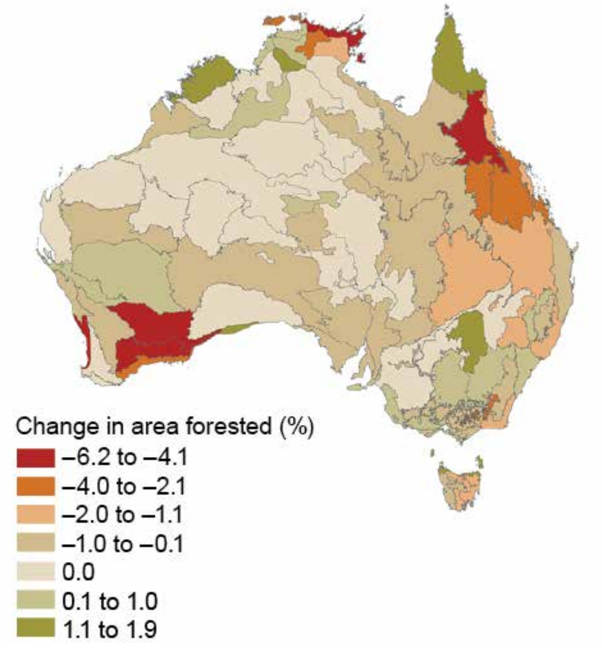
- clearing of nonremnant native vegetation increased from about 54,000 hectares in 2009–10 to about 183,000 hectares in 2013–14
- clearing of remnant vegetation nearly doubled from about 52,000 hectares in 2012–13 to about 95,000 hectares in 2013–14, and has nearly quadrupled since 2009–10
- about 700,000 hectares of high-value regrowth lost protection in 2013, and are currently being cleared
- about 125,000 hectares of remnant vegetation, including about 12,000 hectares of endangered ecosystems, have been remapped as exempt from protection on regulatory maps since 2012.

Land cleared in Queensland's reef catchments increased by 229 per cent from 2008–09 to 2013–14, from 31,000 hectares per year to 102,000 hectares per year. A 113 per cent increase from 2010–11 to 2012–13 coincided with the policy change to reduce compliance activities.

In a 2015 report, the Queensland Auditor-General noted that (Queensland Audit Office 2015):

> *… this result may lead to an increase in the extent of bare ground which, depending on the occurrence of storms and the amount of ground cover provided by the replacement land use, increases the risk of soil erosion within the catchment. Therefore, a rise in tree clearing rates can contribute greater sediment run-off.*

In South Australia, although clearance of native vegetation has stabilised and remaining native vegetation is protected by legislation, the remaining extent is strongly related to previous land use: in the arid natural resource management (NRM) regions (South Australian Arid Lands and Alinytjara Wilurara), 99 per cent of native vegetation remains, while historical agricultural and urban developments in the southern NRM regions have left only about 25 per cent of native vegetation (South Australian Government 2014). This pattern is repeated in other states—that is, less tractable agricultural land often remains largely intact, while land close to settlements or with predictable water availability and fertile soils has been heavily cleared in the past (Figure LAN8).



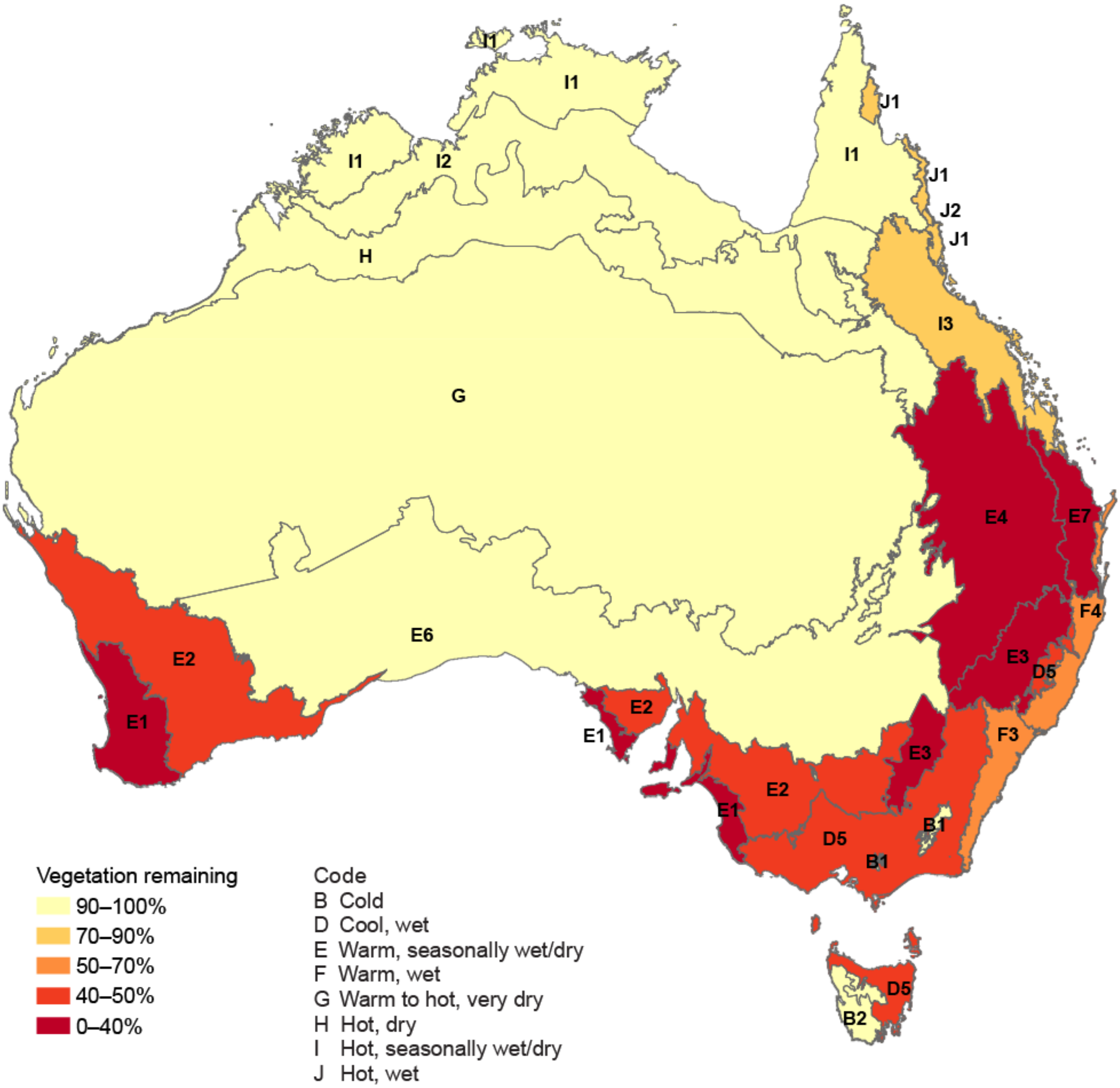
Note: Negative values represent a decrease between 2002 and 2006, while positive values represent an increase between 2001 and 2006.
Source: Biodiversity Assessment Working Group (2009)

Figure LAN8 Continental pattern of Australia's forest cover change, 2002–06

Fire-damaged pencil pine (*Athrotaxis cupressoides*) woodland, Lake Mackenzie, Tasmania
Photo by Chris Emms, Tasmanian Parks and Wildlife Service

Fragmentation of native vegetation

Fragmentation of remnant vegetation following land clearing may adversely affect the quality and persistence of that vegetation, because of the disruption to essential ecosystem processes such as pollination, seed dispersal and regeneration. Smaller fragments also have more edges in proportion to their total area, so opportunities may increase for weed encroachment, changed micro-environmental conditions, ingress of fire from outside the patch and other dynamic processes, further threatening the remnant patch. The National Connectivity Index (DoE 2014a), a nationally consistent approach to characterise fragmentation, has been developed as an instrument for monitoring and prioritising the maintenance and restoration of Australia's heavily modified landscapes. The VAST (vegetation assets, states and transitions) assessment 'classifies vegetation condition by degree of anthropogenic modification from a benchmark condition state' (Lesslie et al. 2010; see Condition) and thus also provides continental-scale information, but only at a relatively coarse scale. In general, fragmentation impacts will be greatest where land clearing has been greatest, both recently (Figures LAN6b and LAN8) and historically (Figure LAN9).



Note: Numbers on the map after the agroclimate letter codes indicate subcategories for each region (after Hutchinson et al. 2005).
Source: Environmental Resources Information Network, Australian Government Department of the Environment and Energy, 2011

Figure LAN9 Percentage of Australia's native vegetation remaining, by agroclimatic region, 2011

Impacts on soils

Soils and vegetation have co-evolved across the Australian landscape over millennia. Vegetation has adapted to the frequently nutrient-poor and sporadically wet soils, and its rooting patterns and litterfall contribute to soil structure and fertility. Clearing of the predominantly deep-rooted native vegetation has many impacts on soil, changing the cycling of water, nutrients, sediments and solutes. Soils take decades, and in some cases centuries, to adjust to the new conditions. Many soils across Australia are therefore still equilibrating to European land use.

Disruption to soil usually results in a significant loss of nutrients. Organic matter is oxidised, and the removal of surface cover (litter and protective vegetation) makes the soil more prone to erosion. Stores and cycles of nutrients adjust under the new land use, but in most cases the net loss of nutrients and leakage is greater than under natural conditions. Soil carbon typically decreases to 20–70 per cent of the pre-clearing amount (Luo et al. 2010). Restoring this very large stock of carbon is now a key focus of programs for mitigating greenhouse gas emissions around the world and nationally (e.g. the Australian Government's Carbon Farming Initiative).

Removal of native vegetation results in major changes to the hydrological cycle, including dryland salinity. The soil also experiences more rapid leaching (loss of water-soluble nutrients), and this can change soil properties and processes (e.g. clays may disperse and reduce permeability). Rising watertables and surface evaporation of soil water increase the salt content of surface soils. A less widely appreciated effect of clearing is that the land surface becomes more uniform—the patchiness of the native system is lost. For example, removing mounds of litter, grass tussocks and rough surfaces leaves a relatively smooth soil surface. This almost invariably leads to more rapid run-off and erosion, less effective water infiltration, and loss of the micro-environments that are required by many species.

Invasive species

Invasive species represent one of the most potent, persistent and widespread threats to the Australian environment. They have a direct negative impact on species through predation, displacement and competition, and also have enormous detrimental effects on the health, viability and functioning of communities, ecosystems and landscapes. These effects occur through both direct and indirect disruption of ecological services such as soil stabilisation, pollination and seed dispersal, and changed fire regimes (see Box LAN3).

Australia's biosecurity system is designed to manage the risk of pests and diseases entering, emerging in, establishing in or spreading in Australia, and causing harm to human, animal or plant health, the economy, the environment or the community.

At Australia's borders, including airports, seaports and international mail centres, the Australian Government coordinates activities that assess and manage potential biosecurity risks before they enter Australia. Onshore and offshore, the Australian Government uses a range of sophisticated technologies and approaches, including research, shared international resources and intelligence, to prevent the introduction and spread of disease, and to manage and contain established pests and diseases.

Invasive species already in Australia are managed through investments and actions at all levels of government, frequently with coordination between the different levels of government. As of December 2015, there were 21 listed key threatening processes under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), 16 of which involve exotic invasive species, and 11 approved threat abatement plans, all of which mention exotic invasive species. Lists of targeted invasive species for various levels of control are also maintained at state and territory level.

The *Biosecurity Act 2015* extends the power of the Australian Government to management of invasive pests, consistent with the United Nations Convention on Biological Diversity. The Act is designed to be flexible and responsive to changes in technology and to perceived risks and threats, and provides for improved collaboration across governments and industries. The legislation includes higher penalties for bringing in prohibited goods if they have the potential to cause harm to the environment.

The Australian Weeds Strategy (Australian Weeds Committee 2007) and the Australian Pest Animals Strategy (Vertebrate Pests Committee 2007) provide national guidance on best practice for weed and vertebrate pest animal management. They aim to guide coordination of effort across all jurisdictions and affected stakeholders, and to inform plans and actions by state and territory governments, local governments, regional NRM agencies, industry, landholders and the wider community.

Box LAN3 Bees—pressures and impacts

Australia has an estimated 2500 species of native bee (Batley & Hogendoorn 2009), and a handful of introduced and invasive bee species. Among the invaders are the western honeybee (*Apis mellifera*), which has been established for more than a century, and is also managed for honey production and crop pollination. The Asian honeybee (*Apis cerana*) arrived in the port of Cairns in 2007 and is still expanding its range. The buff-tailed bumblebee (*Bombus terrestris*) established in Tasmania in 1992, and has occasionally been detected on the mainland, but has not yet established. Some horticultural industries have expressed an interest in commercial use of the buff-tailed bumblebee for greenhouse pollination, which could increase the likelihood that this exotic species would spread to new locations.

There are concerns globally that many pollinators are in decline, in response to pressures such as habitat loss, disease, impact of invasive species and climate change. Like many countries, Australia does not have sufficient historical records of bee distribution or abundance to detect whether native bee species are in decline. Data are available, however, to indicate that the drivers of pollinator decline indicated in other studies are also present in our landscapes.

Loss of bees from landscapes is of concern because of the expected flow-on effects on pollination outcomes. Studies in Australia show changes in pollination rates of native plants that are associated with fragmentation of habitat and impacts of invasive species. Pollination of agricultural crops is mostly done by wild pollinators and so is similarly dependent on landscape context; however, agricultural pollination is sometimes supplemented with managed honeybees.

Australia's population of western honeybees (both managed and feral) is one of the last globally to be free from the devastating varroa mite (*Varroa destructor*). This mite and its associated disease complex have had dramatic effects on honeybees elsewhere in the world, including nearby New Zealand, where it arrived in 2001. It is thought that varroa will eventually establish in Australia. It is expected to dramatically reduce the abundance of feral honeybees and cause economic challenges for beekeepers that will, at least in the short term, reduce availability of hives for crop pollination. Native bees are immune to the disease, and may even increase in abundance in places where they have competed with feral bees.

Western honeybee (*Apis mellifera*) visiting *Eucalyptus shirleyi*
Photo by Dan Metcalfe, CSIRO

Source: Saul Cunningham, CSIRO

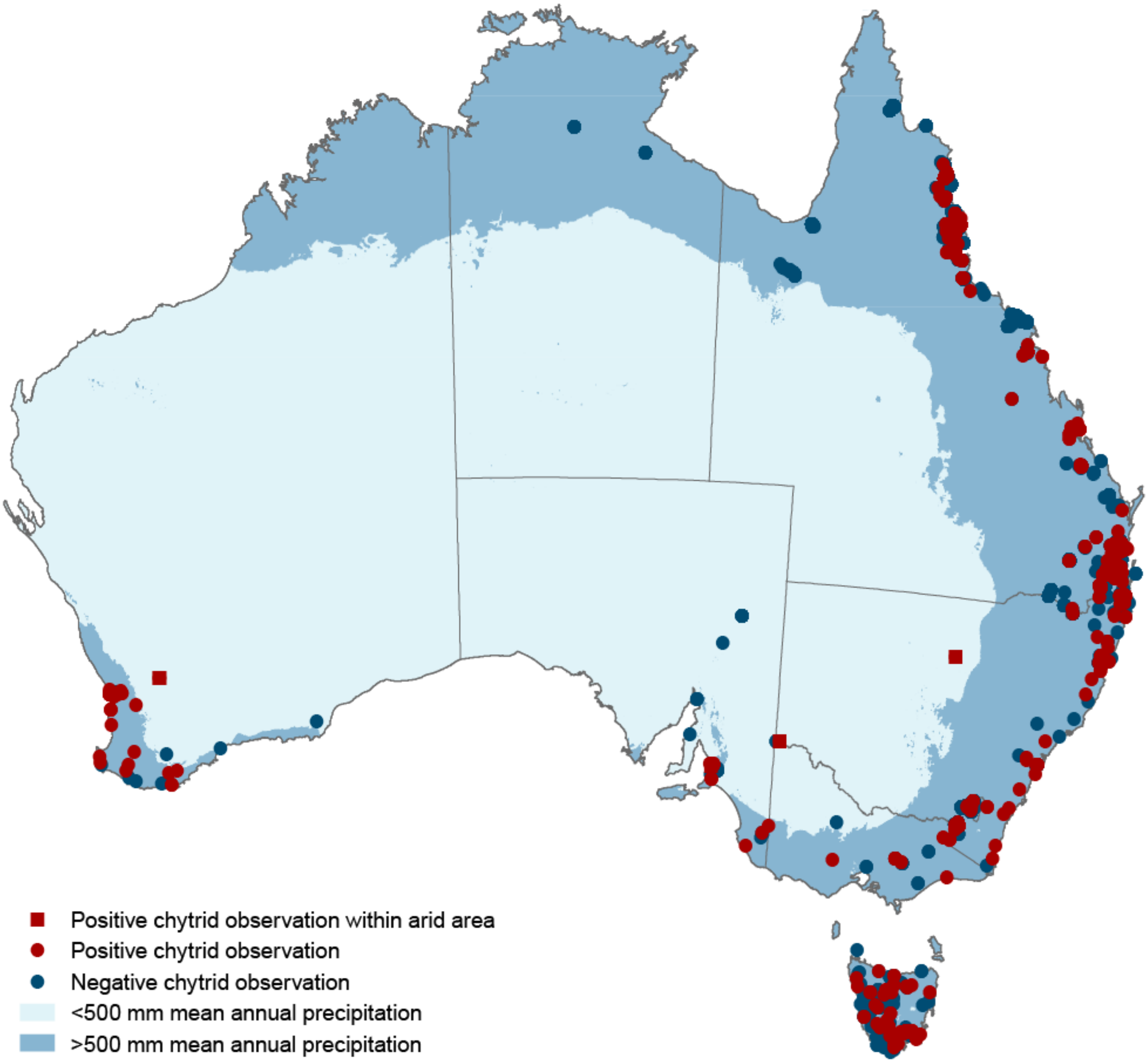
Denuded landscape following fire in native grassland, Coleman River, Cape York, Queensland
Photo by Dan Metcalfe, CSIRO

Pathogens and fungi

Australia is free from many of the most damaging agricultural plant pathogens, as a result of concerted biosecurity efforts at all levels of government, but a few significant pathogens are established in Australia or are near our borders. Most of these potentially threaten commercially grown species (e.g. neck rot of onions—*Botrytis allii*, stem rot of canola—*Sclerotinia sclerotiorum*, stem rust of wheat—*Puccinia graminis*, Panama disease tropical race 4—TR4 of banana). Many can also affect native species and may maintain low-intensity reservoirs of potential infection of commercial crops in native vegetation. Most pathogens that significantly affect native forests and plantations of native tree species are native plant pathogens (MPIG & NFISC 2013). Two pathogens are of particular concern at the national scale: *Eucalyptus* rust or myrtle rust (*Puccinia psidii*—see Box LAN4) and the rootrot pathogen, *Phytophthora cinnamomi*.

Phytophthora, which is a member of the kingdom Chromista or Protista rather than being a fungus, has caused extensive damage to whole vegetation communities, particularly in southern and western Australia. In south-western Western Australia, as many as 2300 of the 5710 native plant species are thought to be susceptible to *Phytophthora* (MPIG & NFISC 2013). Although *Phytophthora cinnamomi* is the species most usually associated with dieback disease, molecular studies are now identifying other *Phytophthora* species in native vegetation, some of which are also proving to be pathogenic (Scarlett et al. 2015).

Potentially, the most important fungal pathogen of vertebrates in Australia at present is the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*), which gained attention in Australia and the Americas in the 1970s by causing rapid declines in native amphibian populations. The disease has been recorded along the east coast, and in south-western Western Australia, Adelaide and Tasmania. A small number of occurrences have been documented from arid habitats (Figure LAN10). Infection rates may be high, and mortality rates attain 100 per cent in some species. Six Australian species have apparently become extinct since the first documented occurrences of chytridiomycosis, and another 7 are at high risk of extinction (Skerratt et al. 2016).



Source: Ocock et al. (2013)

Figure LAN10 Occurrences of chytrid fungus (*Batrachochytrium dendrobatidis*) across Australia, 2013

Box LAN4 Extinctions due to myrtle rust

The pathogenic fungus myrtle rust (*Puccinia psidii*; also known as *Eucalyptus* rust or guava rust) infects a wide range of hosts in the plant family Myrtaceae, which includes many Australian natives (e.g. gum trees—*Eucalyptus*, bottlebrush—*Callistemon*, and tea trees—*Melaleuca*) (Morin et al. 2012, Pegg et al. 2014). It originates from Central and South America, and is now recorded in several countries.

The fungus was first found in Australia in 2010, but its pathway of introduction is not known (Carnegie et al. 2010). Spores are primarily dispersed by wind, although they can also be spread by people, equipment, vehicles and animals. It is now widespread in New South Wales and Queensland, and present in Victoria, and it was detected in Tasmania and the Tiwi Islands of the Northern Territory for the first time in 2015 (Pegg et al. 2014, CRC for Plant Biosecurity 2016). Areas most at risk from myrtle rust—the eastern coast of New South Wales, the Brisbane and Cairns areas in Queensland, and the coastal region from the south of Bunbury to Esperance in Western Australia—were identified by combining a climatic niche model of the fungus with distribution data of its potential Myrtaceae host plant species in Australia (Kriticos et al. 2013).

Latest observations indicate that species that are highly susceptible to myrtle rust may be at risk of extinction. The native guava (*Rhodomyrtus psidioides*), a rainforest species, has already suffered severe crown loss, dieback, and tree and seedling mortality across its entire range in Queensland (Pegg et al. 2014). Extirpation (regional extinction) has already been observed for this species (Carnegie et al. 2015). In a fungicide-exclusion field experiment in a native forest, mature trees of another highly susceptible species, scrub turpentine (*Rhodamnia rubescens*), were killed by myrtle rust in less than 4 years (Carnegie et al. 2015). Whole ecosystems such as *Melaleuca* wetlands may also be at risk, especially considering that several *Melaleuca* species are considered to be highly susceptible based on field survey data (Pegg et al. 2014). Endangered species, such as the angle-stemmed myrtle (*Gossia gonoclada*), that are highly susceptible and only found in areas climatically suited for development of myrtle rust are at particularly high risk of extinction.

Myrtle rust presents a range of questions for science, conservation and management across Australia. Extinction of some Myrtaceae species is likely to become front and centre of the myrtle rust scene in years to come. Management of myrtle rust in natural ecosystems is challenging and impractical because of its windborne spores and wide host range. A key management question for the future is how potential (known or unknown) biosecurity incursions may affect biodiversity conservation, and the level of response required from land managers, including protected area managers. Preventing spread to regions that have not yet been invaded by myrtle rust is paramount—for example, the south-west of Western Australia, which is a biodiversity hotspot with climatic conditions that are highly conducive to epidemics. How can we best manage pathways to unaffected protected areas? In addition, how do we protect susceptible species in areas where myrtle rust is present and thriving? For populations that comprise individuals with innate resistance to the rust, a reduction in genetic diversity will eventuate as myrtle rust slowly removes susceptible genotypes, but at least these species will not become extinct.

The greatest challenge is to prevent extinction of highly susceptible species that have no natural resistance and a range that coincides with the predicted hotspots for myrtle rust epidemics (Kriticos et al. 2013). Reintroduction of extirpated species to the same area will not be a viable, long-term proposition, and translocation to other areas where conditions are not favourable to myrtle rust development will have to be considered.

Beach cherry (*Eugenia reinwardtiana)* with myrtle rust

Photo by Dan Metcalfe, CSIRO

Source: Louise Morin, CSIRO

Pest animals

Although a large number of introduced animal species have naturalised in Australia, a relatively small number are currently the focus of major management programs. Significant investments have recently been made in the control of feral cats and camels, partly in response to a much greater realisation of the impacts of these species, particularly in the arid zone. For example, predation by feral cats is regarded as one of the primary factors in the decline and extinction of a number of native mammal species in Australia, and feral cats are recognised as a potential threat to 74 mammal species and subspecies, 40 bird species, 21 reptile species and 4 amphibian species (Woinarski et al. 2014a). Citizen surveillance for monitoring has also been brought to bear through the FeralScan website developed by the Invasive Animals Cooperative Research Centre (CRC) and partners, which is collating data on 16 feral animal species and hosts more than 50,000 community records.

Currently, the 2007 Australian Pest Animal Strategy (Vertebrate Pests Committee 2007) is being revised following a review completed in 2013 (Community Solutions 2013).

The European rabbit (*Oryctolagus cuniculus*) is Australia's most costly vertebrate pest animal, estimated to cause damage of more than $200 million to agriculture every year. Rabbits are also linked to more than 300 threatened native species. The impact of rabbits is predominantly through soil erosion, modification of soil structure and loss of vegetation. A biocontrol program has operated through the Invasive Animals CRC since 2005, achieving nearly $6 billion of savings associated with reduced rabbit populations and reduced impacts on agriculture. Despite this, rabbit numbers are now increasing as a result of increasing resistance to the biocontrol agent rabbit haemorrhagic disease virus (RHDV1 v351). Release of a new strain of the virus (RHDV1 K5) is currently under consideration by the Australian Government Department of the Environment and Energy, subject to review and public consultation.

A national survey conducted in 2014–15 showed that average stock losses and control costs for wild dogs ranged from $22,900 per year for a small property to $1,940,000 per year for large (pastoral) properties (WoolProducers Australia 2014). In response, the Australian and Western Australian governments, supported by livestock producers, their representative organisations and government agencies, have launched the National Wild Dog Action Plan (WoolProducers Australia 2014) to guide the implementation of a nationally agreed framework for a strategic and risk-based approach to wild dog management. Most other states and territories also have wild dog or pest animal management plans in place.

More controversially, control of wild horses in the Snowy Mountains has been associated with extensive public consultation by the New South Wales Office of Environment and Heritage, following a thorough review of the 2008 Kosciuszko National Park Horse Management Plan and development of a new Kosciuszko National Park Draft Wild Horse Management Plan (NSW OEH 2016). The consultation explored the deeply polarised views held by major stakeholder groups about whether, and how, wild horses should be managed.

Feral goats, pigs and buffalo also exert considerable damage on soil and vegetation through trampling, browsing and erosion. Introduced invertebrates also pose threats to biodiversity, agriculture, infrastructure and people (see Box LAN5).

Weeds

Weeds continue to have a negative impact on:

- the productivity of Australian agriculture and forestry
- the natural environment, through impacts on biodiversity, ecosystem function and environmental health, and promotion of bushfires
- access to sites of significant Indigenous cultural heritage
- public health, through toxicity, allergic reactions and respiratory diseases.

An independent review of the 2007 Australian Weeds Strategy concluded that the strategy was effective in prioritising weeds and weed management problems, and implementing solutions for priority weeds and weed problems (Community Solutions 2013). It was less successful in achieving direct on-ground weed management, particularly in failing to implement action against emerging weed threats, to communicate to stakeholders the importance of their engagement in addressing national weed problems, and to establish nationally consistent legislation to address weed problems. The Invasive Plants and Animals Committee is revising and updating the strategy, whose release is imminent.

Box LAN5 Pest ant species in Australia

Twenty-three exotic ant species have established in Australia. An additional 3 species are subject to eradication programs that aim to remove them completely from Australia and prevent their establishment. Another 5 are the focus of more localised eradication efforts. Because of their severe impacts, 2 ant species are listed as key threatening processes under the *Environment Protection and Biodiversity Conservation Act 1999*, and a third is categorised as a key threatening process by novel biota.

The red imported fire ant (*Solenopsis invicta*) has been undergoing eradication measures since 2001 at a cost to date of more than $400 million. Without an eradication program, fire ants would eventually infest all states of Australia, and their impacts could potentially surpass the combined effects of many of Australia's current worst invasive pests (rabbits, cane toads, foxes, camels, wild dogs and feral cats—which cost Australia an estimated $964 million each year). Despite the increased biosecurity focus on the red imported fire ant, 7 incursions have been detected to date in Australia, 4 of which were within the past 2 years.

No ant species has ever been entirely eradicated from Australia, but all known populations of 2 species (electric ant—*Wasmannia auropunctata*, and browsing ant—*Lepisiota frauenfeldi*) are likely to be fully eradicated in the next few years. Australia is the world leader in dealing with exotic ants, having achieved 78 per cent (113) of localised eradications in the world.

Many of the exotic ant species present in Australia are considered to be among the worst invasive species in the world because of their significant effects on biodiversity, agriculture, infrastructure and people. Two recent vertebrate extinctions on Christmas Island are believed to be partly attributable to the exotic yellow crazy ant (*Anoplolepis gracilipes*). This species is also present on mainland Australia, including in Queensland's Wet Tropics World Heritage Area, where an infestation was identified in 2012. In 2013, the Wet Tropics Management Authority received more than $2 million over 5 years under the Caring for our Country program to eradicate a large infestation within the Wet Tropics World Heritage Area; another $8.8 million has just been earmarked by the Australian Government for the next 3 years.

Yellow crazy ant (*Anoplolepis gracilipes*)

Photo by Phil Lester, Victoria University of Wellington, New Zealand

Box LAN5 (continued)

Aerial baiting on Christmas Island to control yellow crazy ants
Photo by Ben Hoffmann, CSIRO

Source: Ben Hoffmann, CSIRO

The list of Weeds of National Significance (WoNS) was updated in 2012 from 20 to 32 WoNS (see Table LAN1), which includes more than 40 species within the 32 weed groups. Strategic plans for WoNS (2012–17) have been published, and management manuals have been released for the new WoNS species. An additional 28 non-native weeds that have established naturalised populations in the wild have been added to the National Environmental Alert List. These are species that are in the early stages of establishment and have the potential to become a significant threat to biodiversity if they are not managed.

Although understanding of the pressures exerted by weeds on the landscape is increasing, there is no evidence that the rate of naturalisation of alien species is increasing—the number of naturalised species increased linearly between 1880 and 2000 (Dodd et al. 2015). This generalisation is reinforced in an assessment of the naturalisation patterns of one group of weeds—tropical invasive grasses. Again, there is no evidence for increased naturalisation rates over time, or with increased trade, for 155 grass species naturalised between 1788 and 1980 (van Klinken et al. 2015).

An emerging issue in all cropping areas of Australia is herbicide-resistant weed populations. In June 2014, at least 39 weed species in Australia were resistant to 1 or more herbicides, and the number of identified resistant species is growing. A herbicide resistance problem can develop through selection of naturally occurring resistant weeds, or through importation of already resistant weeds through flood, animals, or practices such as the purchase of contaminated grain or use of contaminated machinery (Michael et al. 2010). Herbicide-resistant weeds pose a potential threat to both native vegetation communities and agricultural crops. They also threaten the viability of some no-till farming systems that are designed to limit soil disturbance, and thus loss of soil and nutrients through erosion (GRDC 2016).

Weed management is one of the biggest influences on the management of cropping systems. Herbicide resistance is estimated to cost approximately $187 million in additional herbicide treatments in the grains industry, part of the estimated $2573 million per year spent on weed management in this industry. Despite this investment, grain yield loss as a result of weeds is still estimated to be about $745 million per year (Llewellyn et al. 2016).

Table LAN1 Weeds of National Significance

Common name(s)	Scientific name
Alligator weed	*Alternanthera philoxeroides*
Gamba grass	*Andropogon gayanus*
Pond apple, pond-apple tree, alligator apple, bullock's heart, cherimoya, monkey apple, bobwood, corkwood	*Annona glabra*
Madeira vine, jalap, lamb's-tail, mignonette vine, anredera, gulf madeiravine, heartleaf madeiravine, potato vine	*Anredera cordifolia*
Asparagus fern, ground asparagus, basket fern, Sprengi's fern, bushy asparagus, emerald asparagus	*Asparagus aethiopicus*
Climbing asparagus, climbing asparagus fern	*Asparagus africanus*
Bridal creeper, bridal veil creeper, smilax, florist's smilax, smilax asparagus	*Asparagus asparagoides*
Bridal veil, bridal veil creeper, pale berry asparagus fern, asparagus fern, South African creeper	*Asparagus declinatus*
Climbing asparagus fern	*Asparagus plumosus*

Table LAN1 (continued)

Common name(s)	Scientific name
Asparagus fern, climbing asparagus fern	*Asparagus scandens*
Prickly pear	*Austrocylindropuntia* spp.
Cabomba, fanwort, Carolina watershield, fish grass, Washington grass, watershield, Carolina fanwort, common cabomba	*Cabomba caroliniana*
Boneseed	*Chrysanthemoides monilifera* subsp. *monilifera*
Bitou bush	*Chrysanthemoides monilifera* subsp. *rotundata*
Rubber vine, rubbervine, India rubber vine, India rubbervine, Palay rubbervine, purple allamanda	*Cryptostegia grandiflora*
Prickly pear	*Cylindropuntia* spp.
Broom, English broom, Scotch broom, common broom, Scottish broom, Spanish broom	*Cytisus scoparius*
Cat's claw vine, yellow trumpet vine, cat's claw creeper, funnel creeper	*Dolichandra unguis-cati*
Water hyacinth, water orchid, Nile lily	*Eichhornia crassipes*
Flax-leaved broom, Mediterranean broom, flax broom	*Genista linifolia*
Montpellier broom, cape broom, canary broom, common broom, French broom, soft broom	*Genista monspessulana*
Hymenachne, olive hymenachne, water stargrass, West Indian grass, West Indian marsh grass	*Hymenachne amplexicaulis*
Cotton-leaved physic-nut, bellyache bush, cotton-leaf physic nut, cotton-leaf jatropha, black physic nut	*Jatropha gossypifolia*
Lantana, common lantana, kamara lantana, large-leaf lantana, pink-flowered lantana, red-flowered lantana, red-flowered sage, white sage, wild sage	*Lantana camara*
African boxthorn, boxthorn	*Lycium ferocissimum*
Mimosa, giant mimosa, giant sensitive plant, thorny sensitive plant, black mimosa, catclaw mimosa, bashful plant	*Mimosa pigra*
Chilean needle grass	*Nassella neesiana*
Serrated tussock, Yass River tussock, Yass tussock, nassella tussock (New Zealand)	*Nassella trichotoma*
Prickly pear	*Opuntia* spp.
Parkinsonia, Jerusalem thorn, jelly bean tree, horse bean	*Parkinsonia aculeata*

Table LAN1 (continued)

Common name(s)	Scientific name
Parthenium weed, bitter weed, carrot grass, false ragweed	*Parthenium hysterophorus*
Mesquite, algaroba	*Prosopis* spp.
Blackberry, European blackberry	*Rubus fruticosus* aggregate
Delta arrowhead, arrowhead, slender arrowhead	*Sagittaria platyphylla*
Willows, except weeping willow, pussy willow and sterile pussy willow	*Salix* spp. except *S. babylonica*, *S.* × *calodendron* and *S.* × *reichardtii*
Salvinia, giant salvinia, aquarium watermoss, kariba weed	*Salvinia molesta*
Fireweed, Madagascar ragwort, Madagascar groundsel	*Senecio madagascariensis*
Silver nightshade, silver-leaved nightshade, white horse nettle, silver-leaf nightshade, tomato weed, white nightshade, bull-nettle, prairie-berry, satansbos, silver-leaf bitter-apple, silverleaf-nettle, trompillo	*Solanum elaeagnifolium*
Athel pine, athel tree, tamarisk, athel tamarisk, athel tamarix, desert tamarisk, flowering cypress, salt cedar	*Tamarix aphylla*
Gorse, furze	*Ulex europaeus*
Prickly acacia, blackthorn, prickly mimosa, black piquant, babul	*Vachellia nilotica*

Assessment summary 2

Regional and landscape-scale pressures affecting the land environment

Component	Summary	Assessment grade				Confidence		Comparability
		Very high impact	High impact	Low impact	Very low impact	In grade	In trend	To 2011 assessment
Bushfire	The incidence of bushfires continues to increase, with more fires and increasing frequency of return. Funding initiatives to support controlled fires earlier in the season, including fires for ecological purposes or Indigenous management practices, may reduce extent and intensity, but may also increase return times in some northern areas. In the south, infrastructure and residential developments continue to complicate fire management opportunities		↙			●	●	◆
Land clearing	Land clearing, although declining, is still a significant cause of environmental disturbance across Australia, particularly in Queensland	—				●	●	◆
Invasive species—diseases	Although many of the world's worst diseases have been excluded from Australia to date, several fungal pathogens continue to have very significant impacts on native flora and fauna, with knock-on effects on native vegetation and managed systems		↙			●	●	◆
Invasive species—animals	The review of the Australian Pest Animal Strategy and other studies suggest that the challenges and impacts created by pest animals are as pertinent today as they were in 2007 when the strategy was released. We are still facing new incursions of invasive animals and expansion of the range of existing pest animal species		↙			●	●	◆

Assessment summary 2 (continued)

Component	Summary	Assessment grade (Very high impact / High impact / Low impact / Very low impact)	Confidence (In grade / In trend)	Comparability (To 2011 assessment)
Invasive species—plants	Expansion of the list of Weeds of National Significance, recognition that some national eradication targets are now unachievable, and an enormous naturalised species pool from which new weeds may emerge as environmental conditions change suggest no diminution of the threat posed to agriculture or the environment			

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very low impact:** There are few or negligible impacts on land environmental values
- **Low impact:** Current and expected impacts are not widespread, and may affect only a small number of land environmental values
- **High impact:** Current and expected impacts are widespread, and may irreversibly affect land environmental values
- **Very high impact:** Current and expected impacts are widespread, and will irreversibly affect land environmental values

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- **Not previously assessed**

Contemporary land-use pressures

Grazing

Almost two-thirds of land in Australia has been modified for human uses, primarily grazing of natural vegetation. Livestock grazing accounts for 82 per cent of the area of land used in agriculture, more than one-third of which is in Queensland (ABS 2016c). Environmental issues associated with sheep and cattle grazing include habitat loss, surface soil loss, salinity, and soil and water quality issues. Grazing pressures can also result from feral and native animals, such as goats, camels, rabbits and kangaroos.

Use of grazing land showed a slight decline from 2013–14 to 2014–15 of about 7 per cent; more than one-quarter of this reduction was a reduction in grazing of improved pastures (ABS 2016c). The size of the national cattle herd also declined (Thomas 2016).

Agriculture

Cultivation

Cultivation can benefit agriculture by controlling weeds and pests, and by creating suitably sized soil aggregates for a good seed bed. However, cultivation also disrupts microbiological activity and causes oxidation of organic matter. Its effect on soil organisms and organic matter has been likened to a fire through ploughed soil: cultivation causes a decline in organic matter, which can lead to a general loss of fertility, unless counteracted by actions such as using fertilisers and rotating crops or pastures to restore organic matter levels. Loss of organic matter often leads to soil structural problems, such as surface sealing and hard-setting. Excessive cultivation was widespread during the first half of the 20th century, and still remains a problem in some locations.

Conservation agriculture is a set of soil management practices that minimise the disruption of the soil's structure, composition and biodiversity. During recent decades, techniques of conservation agriculture have been developed that emphasise retention of crop residues, appropriate rotations with legumes and reduced tillage, or even no tillage. In these systems, seed is drilled directly into the soil, minimising disturbance of soil structure and biota, oxidation of organic matter and the threat of erosion. Maintaining soil cover on sloping land is especially important to protect against erosive rainfall. These changes have a major influence on soil condition and trend. Although declines in uptake of conservation agriculture (e.g. direct drilling) have been reported (Darbas et al. 2013), in some jurisdictions the proportion of cropping land sown using no-till methods increased from 16 per cent in 1999 to 67 per cent in 2013.

Nutrient management

Continuous dryland cropping increases run-off and causes erosion, and long-fallowing dryland cropping contributes to rising watertables. Irrigated agriculture also contributes to rising salinity levels, with run-off of sediments, nutrients and pesticides. Maintaining vegetation in riparian zones helps to reduce nutrient run-off, trap sediments and reduce erosion, particularly erosion due to summer rainfall (Darbas et al. 2013). There is also some data to suggest that wetlands have a role in sequestering nutrients from water, although this may involve accumulation in wetland soils, with the potential for remobilisation during flood events (McJannet et al. 2012).

Conservation agriculture practices have the potential to improve crop yields while maintaining soil ecological health. The minimum-tillage and direct-drilling practices of conservation agriculture, which reduce water erosion through minimal disruption of soil, are widely practised across central and southern New South Wales, south-eastern South Australia, Victoria and Tasmania (Peterson et al. 2014). Nationally in 2014–15, the most common land cultivation practice for crops and pasture was 'zero or minimum till' (i.e. no cultivation apart from sowing). Of the pasture land cultivated, 2.3 million hectares received no cultivation apart from sowing, and, of the crop land cultivated, 12.4 million hectares received no cultivation apart from sowing. The use of 3 or more cultivations was the least reported cultivation practice in 2014–15 and had the largest decrease of all cultivation practices, falling by 31 per cent to 660,000 hectares since 2013–14 (ABS 2016c).

The most common crop residue management practice reported in 2014–15 was for standing residue to be retained, which was undertaken on 7.4 million hectares of crops. This practice was followed by residue retained on the ground and residue grazed off, with each reported to be used on 4.8 million hectares of crops. There was a 16.7 per cent decrease in stubble being incorporated into the soil and a 3.5 per cent decrease in stubble being removed by hot burn in 2014–15 compared with 2013–14.

Rates of adoption of conservation agriculture have decreased in the Queensland Murray–Darling Basin catchments, in part as a result of reduced soil extension services, unclear profitability and, possibly, costs of practices. Similarly, although understanding of the farming practices that result in soil erosion and salinity is high in the New South Wales Murray–Darling Basin, adoption of conservation agriculture is low and sometimes decreasing (Darbas et al. 2013).

Production forestry

Industrial plantations are typically made up of single species, often exotic to the region. They have a range of impacts on the environment, from altering local biodiversity to changing soil chemistry to increasing erosion during harvesting and planting. The more extensive native forest production estates (forests available and suitable for commercial wood production) rely on selective harvest of target species. They arouse controversy mainly because of their interruption of ecosystem processes that are critical to some species—for example, selective harvest of mature trees will reduce the population of overmature, and subsequently dying and dead, trees, which are critical in providing large nesting hollows for some birds and marsupials, as well as providing habitat for wood-boring invertebrates and their larvae.

Industrial plantation forests cover 2 million hectares, and native forest production estates cover 36.6 million hectares, 7.5 million of which are public, and 29.1 million of which are leasehold and private (ABARES 2014). It should be noted that the most significant source of native forest wood products is the public multiple-use forests.

Urban and rural residential use

As our population grows and expectations for a higher standard of living increase, urban encroachment continues to cause an iterative loss of strategically valuable agricultural lands in local government areas across most states and territories. Various policies and planning mechanisms are now in place to protect and maintain remaining areas, with all states and territories having specific legislation to enable spatial land-use planning. However, there is ongoing pressure for the sale of agricultural land and consequently an increase in land-use conflicts at the peri-urban boundary. Urban and peri-urban expansion into greenfield sites has an impact on high-value agricultural floodplains around our non–capital cities. As demand for agricultural products increases and there is growing recognition of the need to address the issue of urban encroachment on agricultural land, some jurisdictions are imposing tighter controls on land releases. For example, Tasmania has a State Policy on the Protection of Agricultural Land (2009), which aims to conserve and protect agricultural land so that it remains available for the sustainable use and development of agriculture, recognising the particular importance of prime agricultural land.

Horticultural areas are often located near large urban centres for access to markets and distribution hubs. Encroachment of peri-urban development on horticultural areas can result in pressure on growers to change or cease farming practices that cause odour, noise or dust. Peri-urban areas can also host pests and diseases, posing a biosecurity risk to enterprises.

Local government zoning to prevent such issues may mean that horticultural areas are rezoned as rural, which can limit land value (Horticulture Australia 2006).

Mining

Australia has a significant mining industry, with the sector contributing 8 per cent of gross domestic product in 2012—the fourth largest single sector (ABS 2012a). Although 2014–15 was a period of significant downturn, mining is still a major industry in many regions, particularly in Western Australia, Queensland and New South Wales.

Environmental management in the mining industry before the 1970s was inadequate, and the legacy included contaminated and degraded land with chronic environmental problems. There are also an estimated 50,000 abandoned mines on public and private land in Australia, ranging from single shafts to large complexes (Unger et al. 2015). Inadequate resources are available to rehabilitate them all.

Environmental impacts are now more actively managed, as a result of tighter environmental regulation and the need for companies to obtain a 'social licence to operate'—this is the set of demands and expectations held by local stakeholders and broader society for how the industry should operate. However, the industry is still rapidly expanding, and the scale of disturbance in some regions is transforming the landscape and causing profound environmental change. Recent controversial approvals for expansion of mining in the Galilee Basin in Queensland and the Hunter Valley in New South Wales had been challenged, in part on the basis of their environmental impacts, including on-ground impacts, air pollution, greenhouse gas emissions associated with combustion and, for the Galilee Basin, the potential risks of contamination of the Great Barrier Reef as a result of shipping from the Abbott Point Terminal.

Unconventional gas—coal-seam gas (CSG), shale gas and tight gas—offers significant current and future energy resources, with CSG, in particular, being developed in the major coal basins of eastern Australia. Although the footprint of individual wells may be limited, concern has been raised that, in the Bowen and Surat basins in Queensland, which contain almost two-thirds of Australia's known CSG reserves, the impact of CSG development will add to existing ecologically threatening processes—such as fragmentation, clearing, increased invasive species and changed fire regimes—in a region that is already highly disturbed (Ponce Reyes et al. 2016). Such concern about cumulative impacts has led to consideration of regional planning initiatives to ensure strategic and coordinated approaches to both development and monitoring of impacts (WA EPA 2014). The $60 billion already invested in infrastructure to facilitate exploitation in Queensland has also triggered significant regulatory change, both to ensure safe operation and to meet public concern about the environmental and social impact of the industry (Towler et al. 2016).

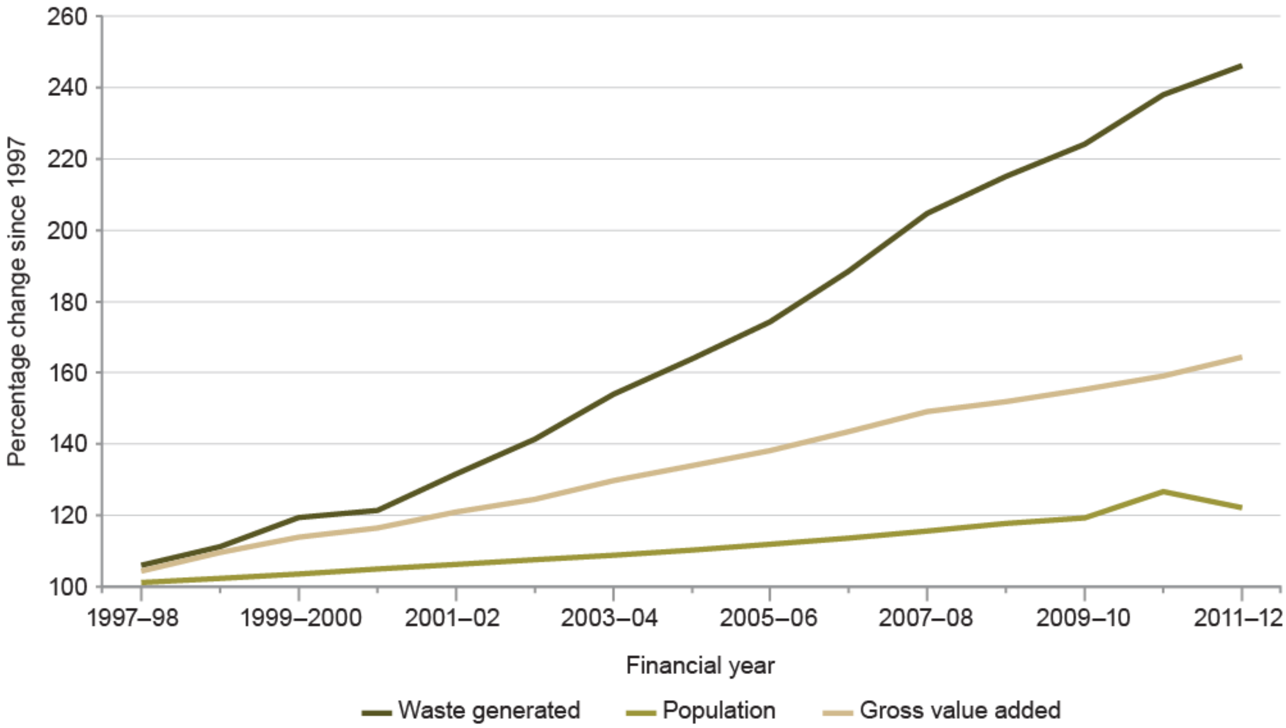
Waste disposal and contamination

Burying waste has been the most common form of waste management in Australia since urban incineration was phased out in the 1940s and 1950s. Since the 1990s, the siting, design and operation of landfill sites have faced tightening environmental regulation and economic pressures. As a result, the number of active landfill sites has been reduced, their average size has grown, and they are increasingly owned and operated by large private companies. Nearly 500 landfill sites are reported across mainland Australia and Tasmania (Pickin 2013).

From 1997 to 2012, the population of Australia increased by 22 per cent, gross value added (the value of goods and services produced in an area, industry or sector) increased by 64 per cent, and waste generation increased by 145 per cent (ABS 2013; Figure LAN11). During 2009–10, 53.7 million tonnes of waste were generated within the Australian economy. The largest contributor to this total was the construction industry, which produced more than 16.5 million tonnes, much of it masonry. The estimated 8.4 million households in Australia produced about 1.5 tonnes of waste each, totalling 12.4 million tonnes. Nearly half of all waste from households was organic waste, and almost a quarter was paper and cardboard waste. Of the total waste generated in 2009–10, 25.2 million tonnes were recovered domestically, 24.9 million tonnes were disposed of to landfill, and 3.7 million tonnes were exported (ABS 2013; Figure LAN12).

The provision of kerbside recycling schemes helped 97 per cent of households to recycle paper and cardboard, glass, plastic bottles or containers, and aluminium or steel cans. The volume of recovered paper increased from 2.0 million tonnes in 2003–04 to 3.1 million tonnes in 2013–14, which reflects an increased recovery rate, from 48.5 per cent of the paper products consumed in 2003–04 to 87.4 per cent in 2013–14 (ABARES 2014).

New initiatives are seeking to combat the environmental and economic cost of sending materials to landfill. For example, it is estimated that every tonne of expanded polystyrene that goes to landfill costs the owner $1500 to $2500. In response, the New South Wales Government has initiated a series of grants to purchase compactors, shredders and storage cages; the resultant polystyrene blocks are sufficiently valuable to make transport to Sydney for resale financially viable (DoE 2014b).



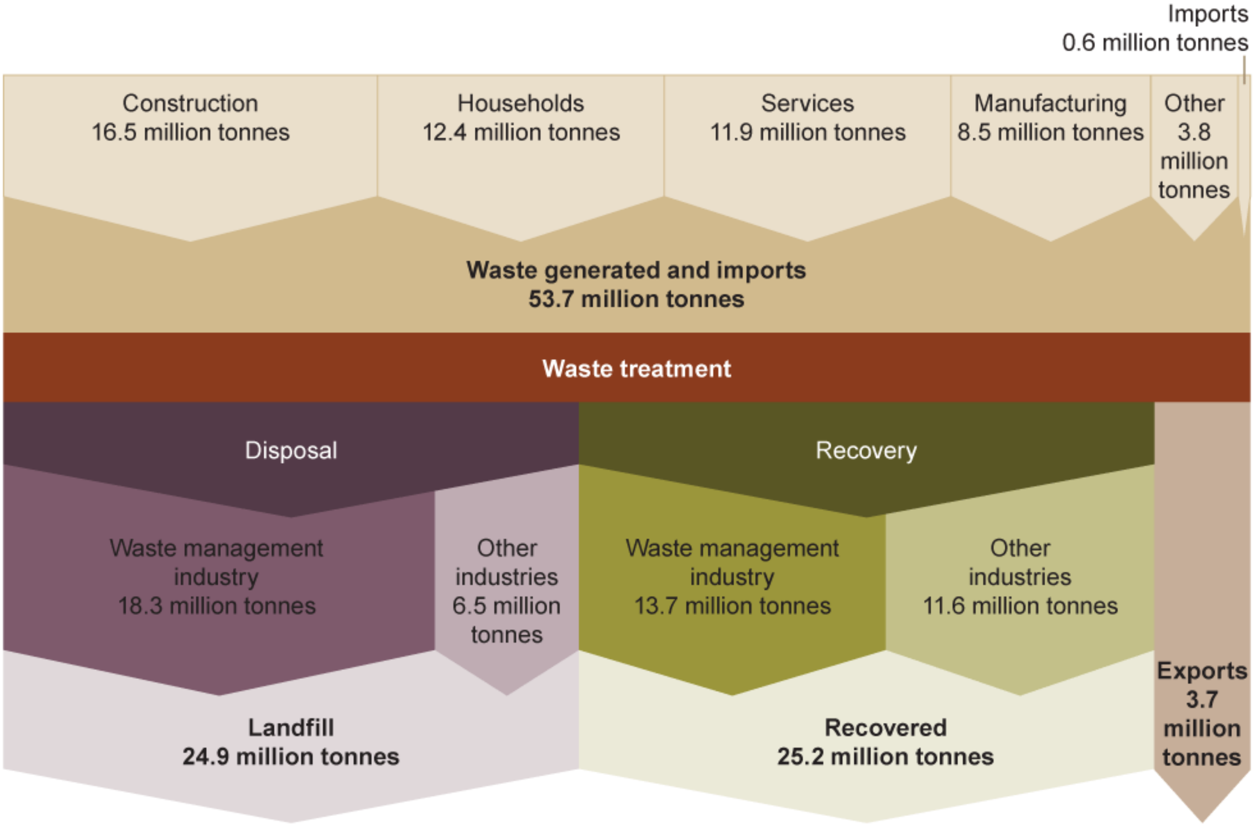
Source: ABS (2013)

Figure LAN11 Waste generation, population and gross value added, 1997–2012

Nature conservation reserves, other protected areas, minimal-use land and Indigenous land

The principal pressures on the environmental values of land under conservation, land not formally protected but subject to minimal use, and land formally owned and managed by Indigenous Australians are grazing by pest animals, grazing by domestic livestock (on those tenures where it is allowed), weed infestation, altered fire regimes and, in the longer term, changed climatic patterns. These pressures are discussed in their relevant sections and in the *Drivers* report.

About 7 million hectares of agricultural land are set aside for conservation or protection purposes, although this fell by nearly 20 per cent in 2014–15 compared with 2013–14 (ABS 2016c).

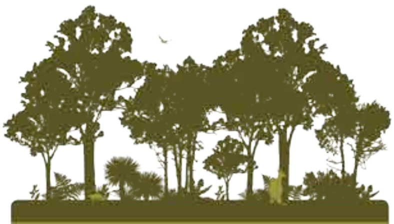


Source: ABS (2013)

Figure LAN12 Waste generated and waste services provided, 2009–12

Deforestation continues around Australia

There are 2 main types of deforestation:



First-time clearing: clearance of old-growth or original forest

Reclearing: clearance of secondary growth (previously cleared and now growing back)

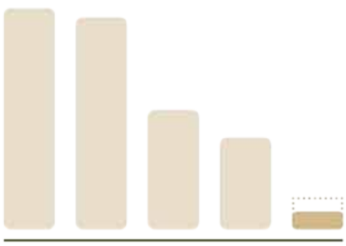
The 2 most heavily cleared forest types are:

Brigalow

Mallee with tussock understorey

Only **20%** of their original forest area remains.

Although clearing has decreased during the past decade, it continues ...



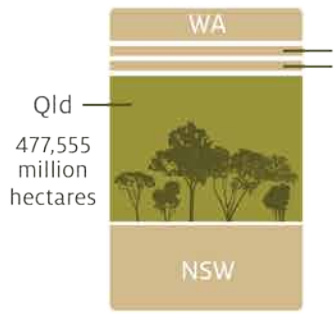
1970–2014
(by 10-year period,
2010–14 partial 5-year period)

First-time clearing

1970–2014
(by 10-year period,
2010–14 partial 5-year period)

Reclearing

... with the majority happening in Queensland



2010–14
Total clearing

Both old-growth and secondary-growth forests have value, and their loss has impacts.

Benefits of forests

- Ecological diversity
- Carbon storage
- Natural recreation
- Cultural values

Pressures

- Need for agricultural land
- Mining
- Urban expansion

Impacts of clearing

- Loss of habitat and biodiversity
- Erosion, increased sediment load in waterways
- Loss of nutrients in soils, rising watertable, dryland salinity
- Disrupted or destroyed Indigenous land management practices

Assessment summary 3

Contemporary land-use pressures on the land environment

Component	Summary	Assessment grade				Confidence		Comparability
		Very high impact	High impact	Low impact	Very low impact	In grade	In trend	To 2011 assessment
Nature conservation areas, other protected areas, minimal-use land and Indigenous land	The size of the conservation estate and the area of land managed by Indigenous organisations continue to increase, although there are still concerns about the adequacy of representation of ecosystem types							
Grazing	Grazing is still a significant major land use, with a range of potential impacts. Slight declines in grazing (mostly intensive, rather than extensive, grazing)							
Dryland and irrigated agriculture	Agriculture continues to disrupt environmental services and threaten integrity of some land types, although improvements in land management continue. Modelling suggests that these management changes will reduce impacts on agricultural systems and downstream environments							
Native production forests	Challenges in achieving agreed management targets could affect biodiversity values, although most environmental service values will still be met							
Plantation forests	A net decrease in the size of the plantation estate (because of declining investment) will have major impacts on the industry, but, because of its small footprint, a relatively minor impact at the national scale							
Urban and rural residential	Ongoing conflict among land-use options, with urban and residential use alienating high-value agricultural land, are likely to continue as population pressures increase around major cities							

Assessment summary 3 (continued)

Component	Summary	Assessment grade (Very high impact / High impact / Low impact / Very low impact)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Mining	Although mining developments have contracted, there are still significant new mine site developments in areas of potential high impact and conflict with other land uses. The legacy of past mining is still large. There is considerable public concern about unconventional gas developments				
Waste disposal	Waste management is mostly well regulated. Increasing re-use is encouraging, but per-person waste production is growing				

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very low impact:** There are few or negligible impacts on land environmental values
- **Low impact:** Current and expected impacts are not widespread, and may affect only a small number of land environmental values
- **High impact:** Current and expected impacts are widespread, and may irreversibly affect land environmental values
- **Very high impact:** Current and expected impacts are widespread, and will irreversibly affect land environmental values

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

State and trends
of the land environment

At a glance

The area of land managed for conservation has continued to expand, in both private and public sectors. This is partly due to a decrease in the area of native forest managed for production of timber and wood products. The area formally owned and managed by Indigenous Australians has also continued to increase, although the majority of such areas are in very remote parts of the continent.

There is increasing investment in use of land and native vegetation for carbon sequestration, carbon emissions avoidance or emissions reductions through appropriate management. In some cases, management for carbon outcomes may be at odds with management for biodiversity outcomes.

Land management practices are improving, particularly in relation to soil management, and reduction of nutrient and pesticide run-off. Some of this is attributable to improved integrated pest management programs, which reduce the required application of pesticides.

Current rates of soil erosion by water across much of Australia exceed soil formation rates, although progress has been made in reducing soil erosion through adoption of soil conservation measures.

A new generation of large-scale soil mapping will inform national mapping and monitoring of carbon, biodiversity, agricultural impact and ecosystem functions in general. Increases in dryland salinity appear to have been slowed by the millennium drought, although a return to wetter conditions is likely to increase spread of dryland salinity. Management of soil carbon is central to maintaining soil health and ensuring global food security, as well as providing an important sink for atmospheric carbon; Australia currently has a lower soil organic carbon stock than other parts of the world. Soil acidification is another challenge facing agriculture, with annual lime application currently lower than required to combat the problem in some jurisdictions.

Impacts of human land use are spread unevenly across the country. Nearly 90 per cent of Australia's native vegetation remains in some form. Vegetation clearing is concentrated in the long-settled agricultural and coastal zones, where more than 50 per cent of native vegetation has typically been cleared. Vegetation condition usually declines along with extent, because increased fragmentation increases the impacts of invasive species and bushfires, and decreases ecosystem functions such as pollination and seed dispersal.

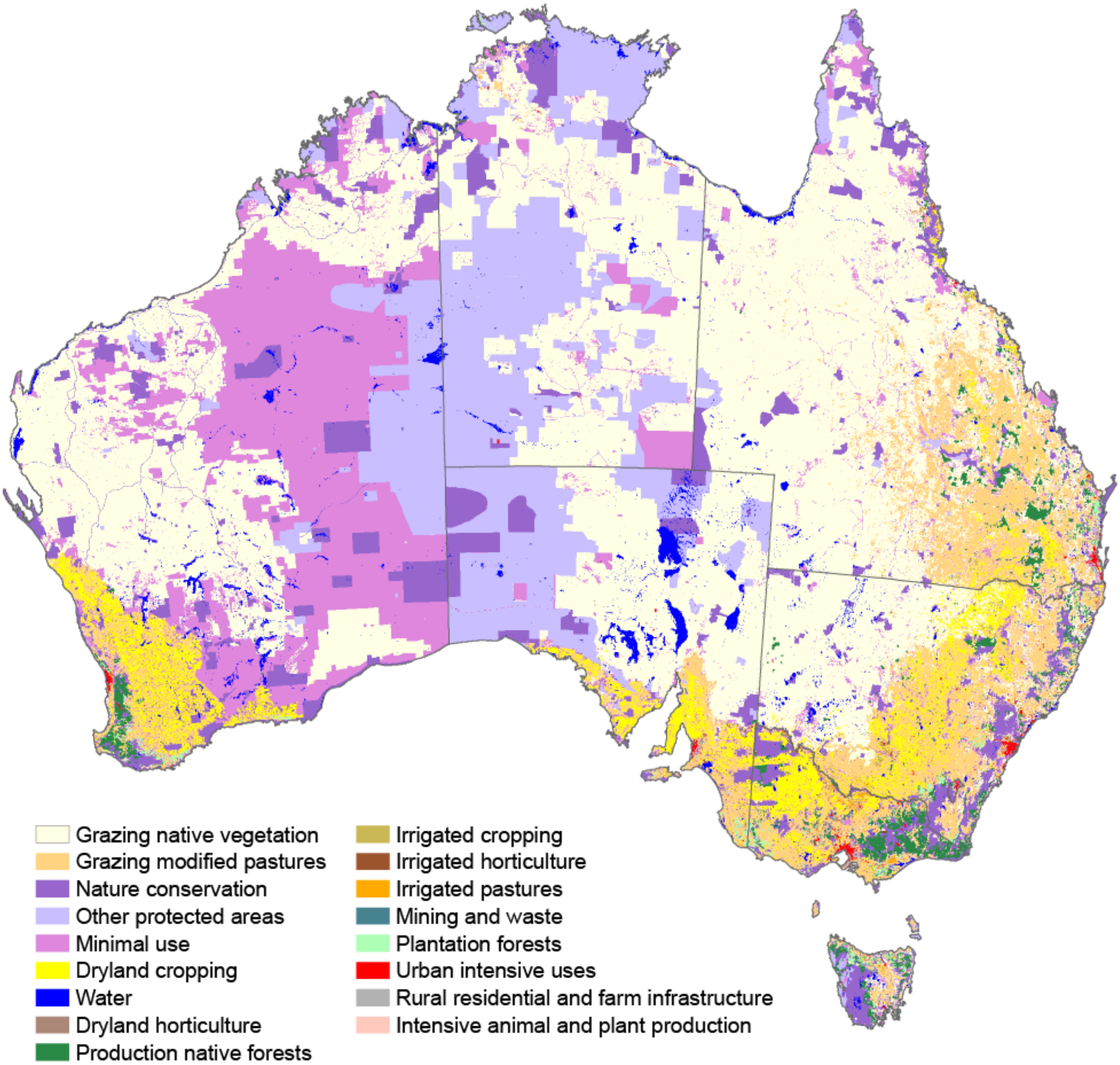
Pristine coastal habitat, western Tasmania
Photo by Ian Cresswell, CSIRO

Australia's land use, soils and vegetation are linked. Each is considered in this section through an examination of its history and current state.

Land use and management

Australia's population is concentrated along the eastern, south-eastern and south-western coastal fringes. To many living in these areas, the daily experience is one of dense urban, industrial and residential zones, fringed by intensive horticulture and agriculture, human-made water bodies and perhaps production forestry. Yet cities account for less than 0.2 per cent of Australia's land area (Table LAN2). The dominant land use, in terms of extent, is livestock grazing of native vegetation (44.9 per cent); grazing of modified pastures accounts for another 9.2 per cent. Nature conservation and other forms of protection, together with minimal use, are the principal use for 38.2 per cent of Australia's land area. Dryland cropping is practised on 3.6 per cent of the land area.

The distribution of these land uses (Figure LAN13) reflects the history and pattern of European settlement; the availability of soil, water and climate to support primary industries; the distribution of other natural resources; and the transport networks that link them. These factors have been reviewed in previous national SoE reports. In brief, intensive agriculture is generally located in higher-rainfall zones within 200 kilometres of the coast, with some exceptions in irrigation areas. Beef cattle grazing is the dominant land use in the extensive tropical and subtropical rangelands of northern Australia. Most dryland agriculture is located south of latitude 21°S on the western slopes of the Great Dividing Range in the east, between the 300–600 millimetre isohyets (lines of equal rainfall), and largely within the confines of these isohyets in South Australia and Western Australia, extending closer to the 250 millimetre isohyet in some areas. Land managed for nature conservation and protection is located primarily in central and northern Australia, and in the forested ranges of the east and south-west of both mainland Australia and Tasmania. These are also the areas where Indigenous Australians have greatest land management responsibilities and interests (Box LAN6).



Source: Australian Bureau of Agricultural and Resource Economics and Sciences, Land Use of Australia 2010–11, used under CC BY 3.0

Figure LAN13 Australian land use at the national scale, 2010–11

The general pattern of land use is well established across Australia (Table LAN2). Estimates of the areas affected are imprecise in some cases, but give a general indication of the scale of different land-use activities across Australia.

Conservation

Since 2011, areas managed for conservation have continued to expand, to around 18 per cent of Australia's land area. During the past decade, Australia's terrestrial conservation estate (International Union for Conservation of Nature categories I–VI) expanded by more than 50 per cent to nearly 140 million hectares. However, calculations suggest that nearly 25 per cent of Australia needs to be protected to meet the strategic goals of the Convention on Biological Diversity (Polak et al. 2016).

Land under conservation management now includes a rapidly growing area dedicated to, and managed for, conservation by private owners (e.g. conservation trusts). The extent of private conservation lands is now more than 7 million hectares.

Indigenous land

The area of land formally owned and managed by Indigenous Australians has continued to increase, to 42 per cent of Australia's land area (see Box LAN6).

Table LAN2 Australian land use, 2010–11

Land use	Area (million hectares)	%
Grazing—natural vegetation	345.0	44.9
Grazing—modified pasture	71.0	9.2
Nature conservation and protected areas (including Indigenous uses)	177.0	23.0
Minimal use	117.0	15.3
Dryland cropping	27.0	3.6
Forests—production native forests	10.0	1.3
Forests—plantation forests	3.0	0.3
Water	13.0	1.6
Agriculture—irrigated cropping	1.0	<0.2
Agriculture—irrigated pastures	0.6	<0.1
Agriculture—irrigated horticulture	0.4	<0.1
Agriculture—intensive animal and plant production	<0.2	<0.1
Agriculture—dryland horticulture	<0.1	<0.1
Residential—intensive (mainly urban) uses	1.4	<0.2
Residential—rural	1.8	<0.3
Mining and waste	<0.2	<0.1
Total	**768.7**	**100.0**

Source: Australian Bureau of Agricultural and Resource Economics and Sciences, used under CC BY 3.0

Effect of severe tropical cyclone *Yasi* on coastal vegetation: erosion, redeposition of sand, and denudation or uprooting of vegetation, Meunga Creek, near Cardwell, Queensland

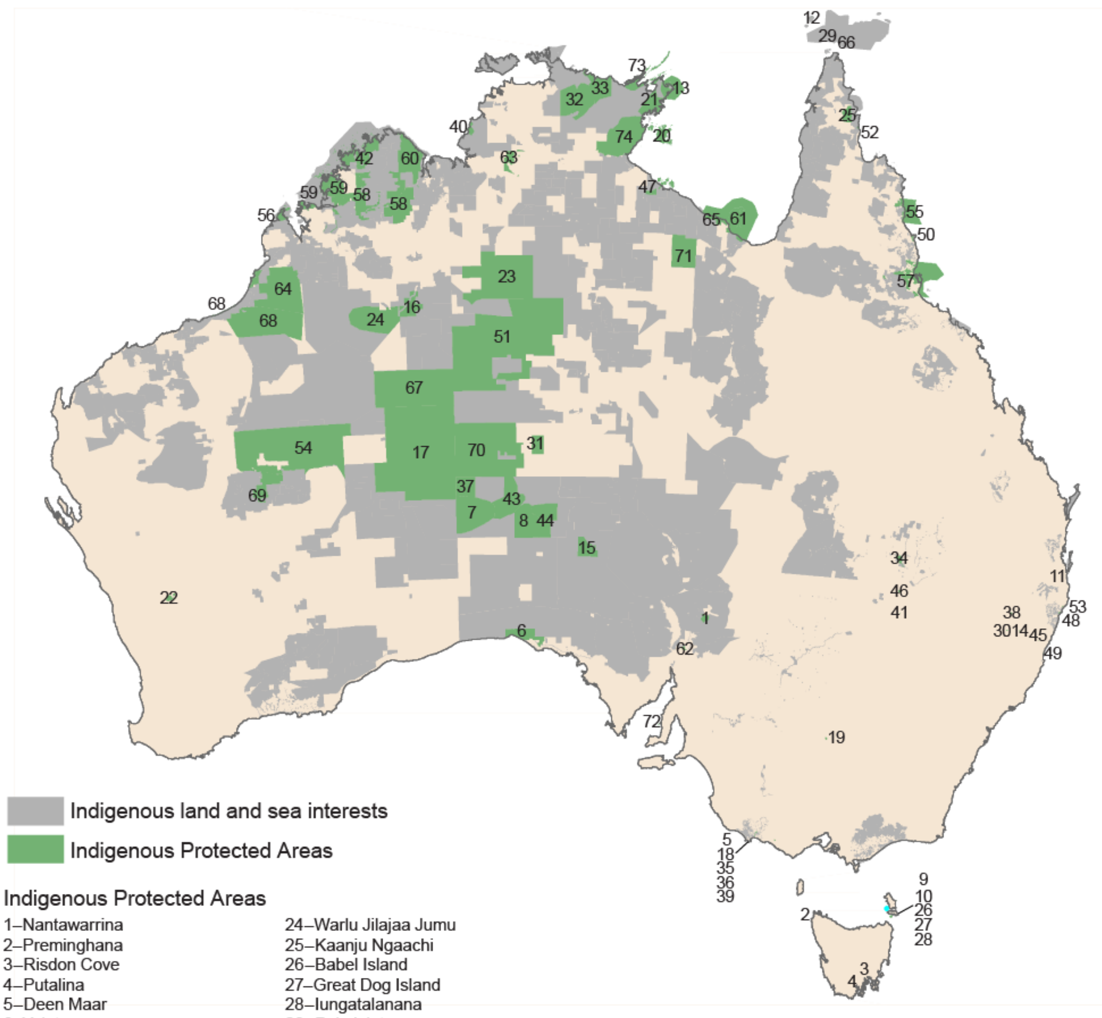
Photo by Dan Metcalfe, CSIRO

Box LAN6 Indigenous land tenure and interests

Indigenous people, their land, and their cultural and natural resource management activities are core contributors to managing Australia's environment. Indigenous lands contain significant levels of biodiversity, and long-term investment in Indigenous land management programs has delivered environmental, cultural and economic benefits (Altman et al. 2007, SVA Consulting 2014, van Bueren et al. 2015).

Indigenous land, water and sea interests occur over 41.8 per cent (3,217,101 square kilometres) of Australia (Figure LAN14). Indigenous people comprise 2.7 per cent of Australia's population, and the proportion of the Indigenous population that is on Indigenous lands is 25.1 per cent. More than 50 per cent of Indigenous land interests lie in very remote areas of Australia and in some of the least commercially viable lands (Altman et al. 2007). Indigenous communities in these remote regions face key challenges for enterprise development and employment (Jackson et al. 2012, Altman & Markham 2014, Woinarski et al. 2014b). Land management and, in places, the carbon economy, may bring potential benefits to Indigenous communities in terms of income, jobs, social welfare, links to community and reconnection with Country. However, land tenure will not necessarily bring economic benefits to Indigenous communities, and other legislative constraints may preclude economic development options for communities.

Box LAN6 (continued)



Sources: Petina Pert (CSIRO), using data from the Australian Government Department of the Environment and Energy website (IPA database 2016) and data from the National Native Title Tribunal, used under CC BY 3.0

Figure LAN14 Indigenous land and sea interests across Australia, and Indigenous Protected Areas, 2016

Agriculture

The sophistication of agricultural land management continues to increase. This is seen in ongoing reductions in the intensity of agricultural chemical use in the cotton industry, due largely to the adoption of genetically modified cotton (Acworth et al. 2008); more careful use of fertilisers in sensitive environments (e.g. catchments of the Great Barrier Reef); and more flexible approaches to grazing management to reduce erosion and increase productivity. The stewardship role of farmers and the part that they play in conserving their land are increasingly recognised.

Horticultural production supply, quality and profitability are threatened by introduced and native pests, diseases and weeds. Integrated pest and disease management uses a number of different integrated methods, rather than relying on a single approach. This is advantageous when managing native animals (e.g. parrots, fruit bats) as pests, and for insect pests and diseases (Horticulture Australia 2006).

Integrated pest management practices aim to integrate all available pest control techniques to produce healthy crops with the least possible disruption to the agro-ecosystem, rather than relying on routine applications of pesticides. First proposed in the 1970s, these practices are becoming more widely adopted in the agricultural sector.

Insect-resistant and herbicide-tolerant cotton, and herbicide-tolerant canola are the 3 types of genetically modified crops in Australia. Insecticide use has been reduced by 85 per cent through the use of insect-resistant genetically modified cotton. However, reduced insecticide use against the cotton bollworm caterpillar (*Helicoverpa armigera*) has allowed other pests to survive and emerge as important pests (Williams et al. 2011). Grain crops (canola and wheat) appear to be able to retain existing yields with reduced insecticide applications, although better forecasting of years with low pest pressure is required to provide growers with opportunities and confidence to reduce insecticide input (Macfadyen et al. 2014).

Native vegetation remnants host a higher density of predatory insects and spiders than crops; crops usually host higher densities of pests (immature and mature) than native vegetation (Parry et al. 2015). Remnant vegetation also provides parasite habitat, which contributes to pest suppression in crops. These biocontrol services reach 125 metres and beyond from native vegetation into crops; however, the spatial pattern of colonisation can be patchy. Reliability of biocontrol increases as the availability of remnant vegetation increases (Bianchi et al. 2015). Management and improvement of remnant vegetation can increase the predator to prey (pest) ratio, which can improve pest control in grain and cotton crops (Bianchi et al. 2013). Retention and management of remnant native vegetation can also maintain populations of native bees (agricultural crop pollinators), which are more abundant and diverse in agricultural landscapes with more remnant native vegetation (especially riparian vegetation) than in those with less native vegetation (Cunningham et al. 2013).

Agricultural practices also aim to protect the soil and prevent sediment movement (see Cultivation). For example, modelled estimates of the nutrient and sediment loads reaching the Great Barrier Reef lagoon suggest that changes to the landscape—grazing, bushfires, and vegetation clearing for agriculture and urban development—will increase deposition to more than 3 times background (pre-European colonisation) levels (McCulloch et al. 2003, Kroon et al. 2012, Waters et al. 2014). Principles and guidelines for managing stocking rates, watering points and groundcover condition aim to improve water quality through best-practice grazing (Bartley et al. 2010, Silburn et al. 2011, Hunt et al. 2014). Significant investment by the Australian Government, state and territory governments, and industry has led to a better understanding of the source and causes of nutrient and sediment increases, and engagement with NRM bodies, industry and farmers is modelled to be potentially achieving significant (10–30 per cent) decreases in sediment loads. A combination of good contextual understanding, participation across the range of stakeholders and adequate funding should thus result in better-quality water reaching the Great Barrier Reef (see Box LAN7). In the Fitzroy Basin in Queensland, adoption of best management practice is high in dryland cropping enterprises as a result of the Reef Water Quality Protection Plan, even though croppers have not received the same resources as graziers and cane growers (Darbas et al. 2013).

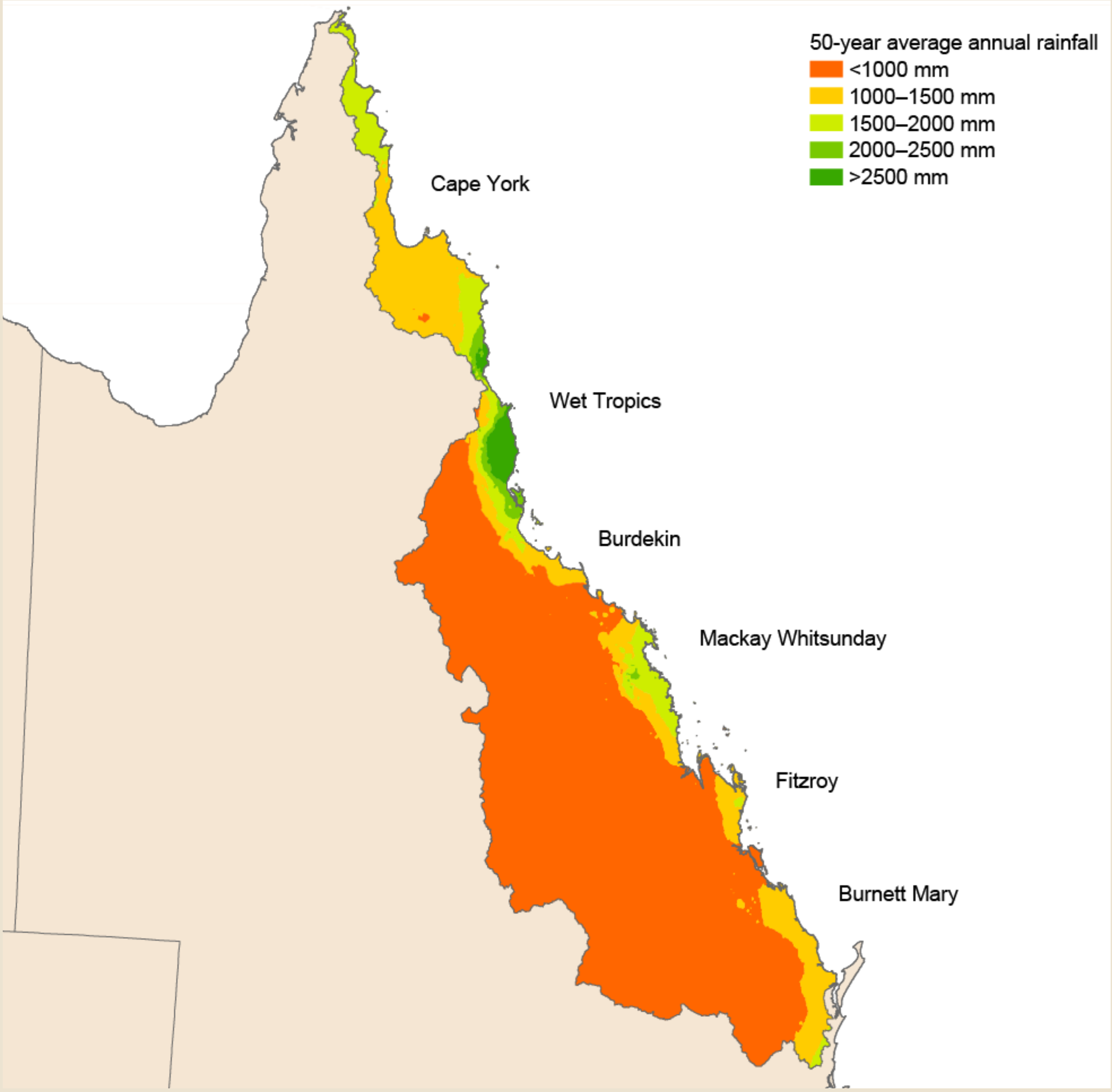
Box LAN7 Land management to reduce sediment and pollutant delivery to the Great Barrier Reef lagoon

The Great Barrier Reef catchments drain an area of 423,134 square kilometres of coastal Queensland, consisting of 6 major catchments and 35 subcatchments, and covering 2300 kilometres from the southern tip to the northern extent (Figure LAN15). The predominant land use is grazing (75 per cent), and agricultural crops account for around another 5 per cent. Modelling estimates for the whole of the Great Barrier Reef for exported loads of total suspended sediments suggest that these have increased to 3 times pre-development loads (Waters et al. 2014), while coral records indicate increases to 5–10 times pre-development loads (McCulloch et al. 2003). The major source of sediment, nutrients and pesticides to the Great Barrier Reef is diffuse-source pollution from agriculture (Queensland Government 2013). This comes largely from the predominantly pastoralist Burdekin and Fitzroy natural resource management (NRM) regions, which contribute more than 70 per cent of the modelled sediment load, and the sugar-growing regions of the Wet Tropics and Mackay–Whitsunday.

Water quality can be improved by adopting best-practice grazing and agriculture practices, although water quality targets cannot be met by this method alone. Groundcover decreases as stocking rates increase, resulting in increased sediment loads (Thorburn et al. 2013, Wilkinson et al. 2014). Off-stream watering points, and fencing and revegetation of riparian strips can all reduce bankside and gully erosion, which is a major source of sediment during high-rainfall events (Olley et al. 2013, Wilkinson et al. 2013). In most cropping systems in Great Barrier Reef catchments, management systems that reduce or eliminate tillage and maximise soil cover, and the use of grassed headlands and sediment traps reduce soil loss. Nutrient losses are best addressed by ensuring that fertiliser applications closely match crop requirements in both amount and timing (Brodie et al. 2013). Herbicide losses can be combated in cropping systems using techniques that reduce soil loss, and by managing timing and mode of application to reduce run-off (Thorburn et al. 2013).

During the reporting period of the Reef Water Quality Protection Plan 2009 (2008–13) and for the first year of the plan (2013–14), modelling indicates that adoption of improved land management practices will have reduced loads to the reef lagoon of total suspended sediments by 12 per cent, particulate phosphorus by 14.5 per cent, particulate nitrogen by 11.5 per cent, and specific pesticides by 30.5 per cent (Queensland Government 2014). More than half of the modelled reduction in sediment load (2008–13) came from the Burdekin NRM region, while 80 per cent of the modelled herbicide reductions were achieved in the Wet Tropics and Mackay–Whitsunday NRM regions (Waters et al. 2014). However, despite some gains, agricultural run-off is still impairing water quality in the lagoon, and the overall condition of the inshore marine environment remained poor in 2013–14 (Queensland Government 2014). Further evaluation of practice changes is continuing; there is scant evidence that modelled reductions have occurred so far, although this is a highly complex system and changes may take years to be realised.

Box LAN7 (continued)



Source: Data from the Bureau of Meteorology, used under CC BY 3.0

Figure LAN15 Great Barrier Reef catchments

Forestry

The area of public native forest managed for wood production has continued to decline since 2011, to around 7.5 million hectares. There has been a corresponding increase in the extent of public native forest in conservation reserves (Davidson et al. 2008).

Plantation forests funded by managed investment contracted significantly to around 400,000 hectares in 2012–13 from 730,000 hectares in 2008–09, which represents around 20 per cent of Australian plantations compared with 36 per cent in 2008–09 (ABARES 2014).

The extent and severity of wildfires in south-eastern Australia have rekindled debate about strategies for fire suppression, how best to balance protection of life and property with protection of environmental assets, residential expansion in forested regions, and the future viability of some native forest–based industries (Teague et al. 2010).

Carbon sequestration

The recent expansion in use of land and vegetation for carbon sequestration, carbon emissions avoidance and emissions reductions has become a mainstream interest for industries and governments (see Box LAN8). The advantages and risks of biosequestration compared with other forms of sequestration (e.g. geological capture and storage) may have a very large impact on future rural land use and management. Models of carbon stocks and flows in native forests managed for timber production, of harvested wood products (including paper), and of long-term storage of harvested wood product wastes in landfill suggest broadly positive benefits when whole-of-system accounts are considered (Ximenes et al. 2016). These benefits include both sequestration—with carbon fixed for the long term in both timber products and timber wastes stored as landfill—and carbon emissions avoidance. For example, use of native timber products for paper pulp has significant greenhouse gas mitigation potential compared with the carbon emissions footprint of imported paper pulp from nonsustainably managed forests in South-East Asia. On balance, careful management of production forests was shown to have a better modelled carbon outcome than conservation management (Ximenes et al. 2016), although challenges remain to show that production management approaches are environmentally sustainable in the long term (Lindenmayer et al. 2015).

Mining

The recent downturn in the mining industry has put some proposed developments on hold, and resulted in the cessation of activities at other sites. A dramatic expansion in coalmining and the CSG industry in some prime agricultural regions has caused conflict because of competition for land and concerns about contamination of, and competition for, water resources. The associated infrastructure and expansion of export facilities are also placing pressure on some coastal environments.

Most of the announced CSG reserves are already committed to the liquefied natural gas industry from 2015–16, with the potential for domestic gas shortages in eastern Australia and the prospect of large increases in gas prices. A consequence is that exploration for shale gas and tight gas has increased, because shale gas is likely to be plentiful and has the potential to be an economically very important additional energy source (Cook et al. 2013).

Increased use of shale gas (and other gas) for electricity generation could significantly decrease Australia's greenhouse gas emissions, based on replacement of coal with gas (Cook et al. 2013). Shale gas, like CSG, has possible adverse impacts on the landscape, soils, flora and fauna, groundwater and surface water, the atmosphere, and human health, through hydraulic fracturing (fracking), habitat fragmentation, disruption of ecological processes, fugitive gas emissions and so on. Changes to the EPBC Act recognised that national environmental assets could be affected by changes to water quality, quantity and availability as a consequence of coalmining or CSG extraction. In response, the Australian Government has invested in a Bioregional Assessment Programme, which is compiling the scientific evidence necessary to support decisions taken by states and territories about the potential impacts of, controls for, and mitigations available for, any new developments (e.g. the New South Wales review by the Chief Scientist and Engineer; O'Kane 2014). Relevant industries have also taken steps to maintain public confidence and obtain a social licence to operate through offsetting impacts of mining developments—for example, the Gas Industry Social and Environmental Research Alliance.

Box LAN8 Savanna burning for reduced carbon emissions

Fires in the savannas of northern Australia release the greenhouse gases methane and nitrous oxide as they burn. These emissions from Australia's savanna fires comprise 2–4 per cent of the National Greenhouse Gas Inventory (Cook & Meyer 2009). Thus, there is potential to use fire management to reduce greenhouse gas emissions by increasing the incidence of early dry-season fires, to reduce the extent of large, high-intensity fires late in the dry season, and to reduce overall fire frequency and consequently the average emissions of greenhouse gases. The approach has been developed as the 'Emissions abatement through savanna fire management' methodology to reduce accountable emissions under Australia's Carbon Farming Initiative.

An example of the implementation of this initiative is the West Arnhem Land Fire Abatement Project, which involves multiple traditional land-owning groups in an area spanning 24,000 square kilometres in the Northern Territory (Cook et al. 2012). The primary goal of the project is to reduce greenhouse gas emissions. During the first 7 years of implementation, the project has reduced emissions of accountable greenhouse gases (methane and nitrous oxide) by 37.7 per cent, relative to the pre-project 10-year emissions baseline (Russell-Smith et al. 2013). Additionally, the project is providing the means to reconnect people to their Country, to keep alive traditions and to adapt them to new circumstances. It is also reducing the impact on biodiversity of decades of out-of-control fires, and providing an opportunity for traditional ecological knowledge and western scientific approaches to jointly inform future land management.

CSIRO is currently working with the Australian Government Department of the Environment and Energy to quantify the increased carbon sequestration that can occur from changing fire management.

Management fire in low-rainfall savanna, central Australia
Photo by Garry Cook, CSIRO

Source: Garry Cook, CSIRO

Built environment

Australian cities and coastal settlements continue to sprawl, despite some successful attempts by local, state and territory governments to manage development to protect biodiversity, good-quality agricultural lands and areas prone to flooding. For example, one of the stated purposes of the *Planning and Development Act 2005* of Western Australia is to 'promote the sustainable use and development of land in the state'. This includes protecting land of agricultural significance from urban and peri-urban encroachment, maintaining appropriate buffers between development and coastal estuarine and water foreshores, and accounting for sea level rise and increased storm surge arising from coastal development. There is also a growing recognition of the value of green space in urban areas for recreation, biodiversity, visual amenity, flood mitigation and other ecosystem services.

Soil

Understanding the current state and condition of Australian soils requires an appreciation of their diversity and their ability to support different forms of land use. It also requires an appreciation of human impacts, not only in recent years and decades, but also on longer timescales of centuries and millennia. This is because the impact of land-use change is long-lasting, soil formation is very slow, and remediation can take decades. Most states and territories now explicitly include a section on soil in their own SoE and NRM report cards. However, there is currently no standard set of indicators for monitoring soil condition, and each jurisdiction uses its own set. The ratings, symbols and reporting regions used are not standardised either between states and territories or with the Australian Government.

Baseline

The environmental baseline adopted throughout much of SoE 2011 was the international pre–industrial revolution baseline (1750). However, for soil, this is problematic because there is limited evidence about the soil's physical, chemical and biological condition at that time, although there is an understanding of soil changes associated with land clearing, and conversion to land uses such as agriculture and forestry. Most assessments of soil change presented here relate to the condition in the 2011 assessment, unless otherwise stated.

A new generation of large-scale soil mapping (see Box LAN9) will inform national mapping and monitoring of carbon, biodiversity, agricultural impact and ecosystem functions in general.

A framework for understanding soil

The major soil types in Australia are summarised using the Australian Soil Classification in Table LAN3. A generalised map of the major soil types (orders) is provided in Figure LAN16.

In this report, we use the hierarchical stratification of Australia's landforms from the Australian Soil Resource Information System (ASRIS). The ASRIS mapping hierarchy divides Australia into 3 physiographic divisions, which are further subdivided into 23 provinces and 220 regions. These broadscale mapping units have similar geological origins, and a characteristic suite of soils and landforms. Even then, a diversity of soils and land management systems often occurs within each region. Therefore, it is only possible to reach general conclusions about the state of the soil for each region—there are always local exceptions.

Key indicators of soil condition

A healthy soil has biological, chemical and physical properties that promote the health of plants, animals and humans, while also maintaining environmental quality (Soil Quality n.d.). The notion of 'soil health' reflects that soil is not an inert growing medium, but a living, dynamic environment, full of microbial and macroinvertebrate life. Many physical and chemical processes that occur in soils are mediated by biological processes, which operate at different rates across the landscape according to the climate, land use and soil type. Results from the current Biomes of Australian Soil Environments (BASE) project (Bioplatforms Australia 2014) should provide useful data for understanding how soil microbial diversity supports healthy soil function.

Soil health is the condition of the soil relative to a set of benchmarks that encapsulate healthy functioning. The key indicators of soil condition in agro-ecosystems are:

- carbon and nutrient content
- acidity (pH) and acidification trend
- soil structure and porosity
- topsoil thickness
- secondary salinity.

Box LAN9 Soil and Landscape Grid of Australia

The new Soil and Landscape Grid of Australia provides gridded data on soil and landscape attributes, along with estimates of uncertainty. Data are provided for 90 metre pixels, and are available for 6 soil depths (0–5 centimetres, 5–15 centimetres, 15–30 centimetres, 30–60 centimetres, 60–100 centimetres, 100–200 centimetres) down to a maximum of 2 metres. The data are in easily accessible raster file formats, which can be downloaded or viewed through the CSIRO data access portal. Attributes available are shown below.

The Soil and Landscape Grid draws together historical and new data generated from sampling, new laboratory measurement techniques, remote sensing and modelling (Grundy et al. 2015). Funded through the Terrestrial Ecosystem Research Network, it is the result of national collaborative research involving CSIRO; the University of Sydney; Geoscience Australia; and Australian, state and territory government agencies. It adds further value to hundreds of millions of dollars worth of investments in soil surveying during the past 50 years.

Soil attributes	Landscape attributes
• bulk density	• slope (per cent)
• organic carbon	• slope (per cent), median, 200 metre radius
• clay	• slope relief classification
• silt	• aspect
• sand	• relief, 1000 metre radius
• pH (water)	• relief, 300 metre radius
• pH (calcium chloride)	• topographic wetness index
• available water capacity	• topographic position index
• total nitrogen	• partial contributing area
• total phosphorus	• multiresolution valley bottom flatness
• effective cation exchange capacity	• plan curvature
• depth of regolith	• profile curvature
• depth of soil	• Prescott index
• coarse fragments	• solar radiation (SRAD), net radiation, January
	• SRAD, net radiation, July
	• SRAD, total shortwave, sloping surface, January
	• SRAD, total shortwave, sloping surface, July

Table LAN3 Australia's main types of soil

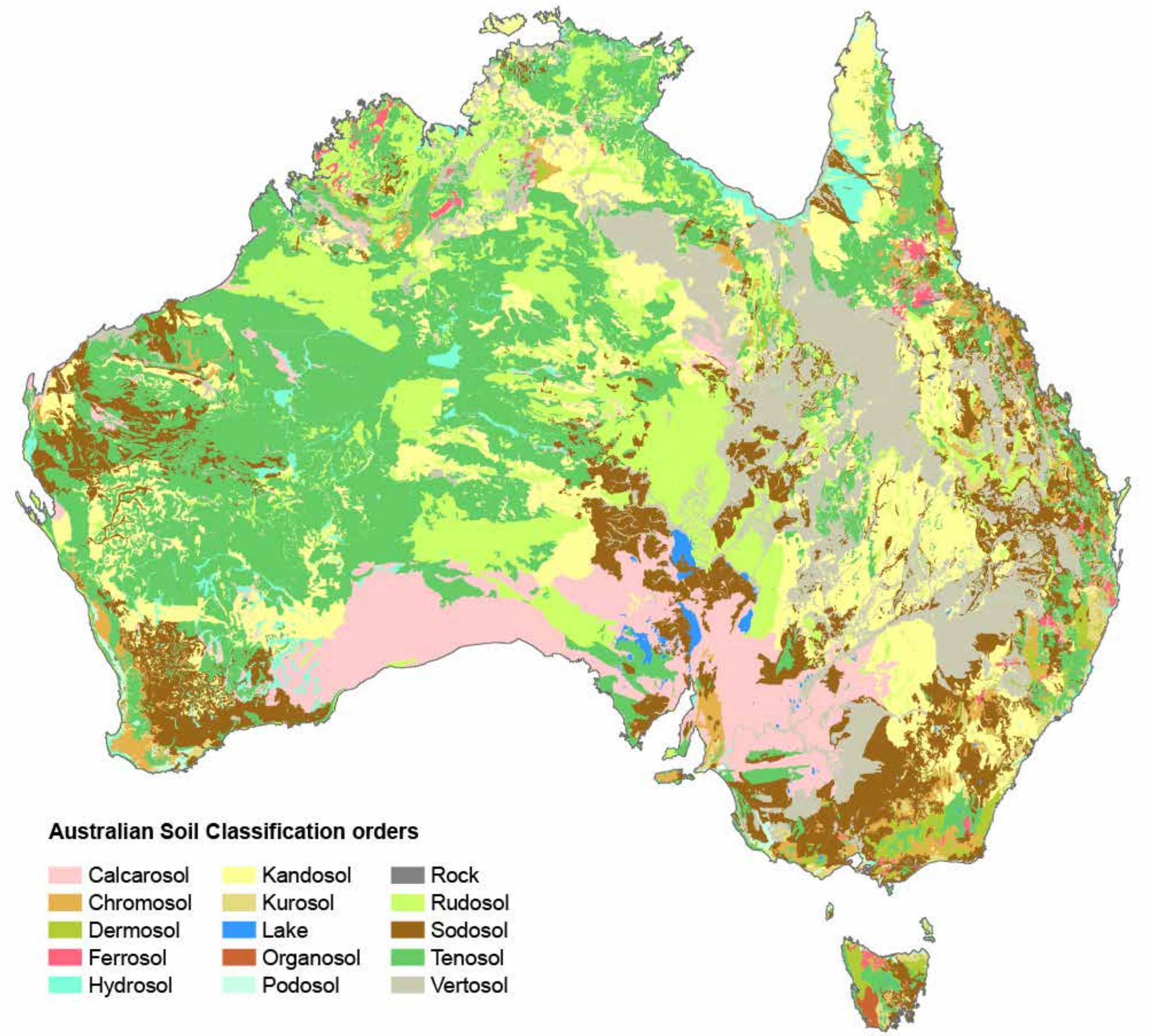
ASC order	Simplified description	Percentage of Australian soil
Anthroposols	Soils resulting from human activities	No data
Calcarosols	Soils dominated by carbonate	9.2
Chromosols	Neutral to alkaline soils with a sharp increase in texture with depth	3.0
Dermosols	Structured B horizons (having a concentration of silicate clay, iron, aluminium and organic material) and gradational to minor changes in texture with depth	1.6
Ferrosols	High iron levels and gradational to minor changes in texture with depth	0.8
Hydrosols	Wet soils	2.2
Kandosols	Strongly weathered earths with minor changes in texture with depth	16.5
Kurosols	Acid soils with sharp increases in texture with depth	1.0
Organosols	Organic soils	0.1
Podosols	Soils with accumulated organic matter, iron and aluminium	0.4
Rudosols	Minimally developed soils	14.0
Sodosols	Soils with sodic subsoils, which are often alkaline, and with a sharp increase in texture with depth	13.0
Tenosols	Slightly developed soils	26.3
Vertosols	Cracking clays	11.5

ASC = Australian Soil Classification

The processes that control these indicators are interrelated to some extent; for example, a soil's thickness, structure, porosity, and carbon and nutrient content determine its susceptibility to erosion.

The carbon and nutrient content reflect the soil's fertility, and its ability to support vegetation and other biota. Native plants are adapted to the natural soil pH, whether it is acid or alkaline. Most crops, however, have a preference for slightly acidic soils (pH 5.5–6.5). Higher acidification can lead to a decrease in crop biomass and protective cover, a concomitant decrease in soil organic carbon and nutrient content, and eventually erosion that results in thinner topsoil.

In Australia, naturally saline or sodic soil occupies 27 per cent of the continent. Anthropogenic secondary soil salinity can result from changes in landscape hydrology due to land clearing, or irrigation with low-quality water and inadequate drainage. The removal of native vegetation changes the hydrological cycle, because trees and shrubs intercept significant quantities of rain—often 10–20 per cent of rainfall fails to reach the soil surface. If the original vegetation has been replaced by shallower-rooted species that use less water (e.g. annual crops and pastures), more water passes through the soil. This may lead to rising groundwater levels and, in some cases, secondary dryland salinity. If the salts are sodium carbonates, problems associated with soil sodicity will result; the soil will become more dispersible and therefore erode more easily.



Source: Australian Soil Resource Information System and Ashton & McKenzie (2001), © CSIRO Land and Water, all rights reserved

Figure LAN16 Generalised map of soil orders for Australia

Carbon dynamics

In light of international agreements such as the Paris Agreement—which emerged from the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCC) in 2015, and governs greenhouse gas emissions mitigation, adaptation and finance from 2020—the management and monitoring of soil carbon is a matter of national and international importance. Putting back an additional 0.4 per cent of carbon into the soil every year could neutralise the impact of greenhouse gases released into the atmosphere. Soil carbon can be a significant source or sink for greenhouse gases, depending on how land is used and managed, and whether the soil carbon is organic or inorganic (Sanderman 2012, Monger et al. 2015). Management of soil carbon is also central to maintaining soil health and ensuring global food security.

The organic carbon content of soil is a key indicator of its health. It is a variable that indicates the functioning of many ecosystem processes (e.g. nutrient and waste cycling, water storage, biodiversity). The carbon comes primarily from plant materials that are created through the capture of atmospheric carbon dioxide via the process of photosynthesis. These organic materials are cycled through the soil, and used by organisms as a source of energy and nutrients. A significant amount of carbon dioxide is returned to the atmosphere as a result of respiration. Increasing soil organic carbon (SOC) leads to an increase in:

- energy supply for microbes, macrofauna and earthworms
- direct nutrient supply to plants (particularly nitrogen, phosphorus and sulfur)
- the capacity of the soil to retain and exchange nutrients
- aggregation of soil particles and stability of soil structure
- water storage and water availability to plants
- beneficial thermal properties
- pH buffering (helping to maintain acidity at a constant level).

The maximum equilibrium carbon content for a soil at a given location is determined by environmental factors such as rainfall, evaporation, solar radiation and temperature. SOC content is generally higher in cool, wet environments, whereas inorganic carbon content, in the form of carbonate minerals, is higher in semi-arid environments. A lack of nutrients, and a limited capacity of the soil to store and supply water can reduce this potential maximum, as can other constraints to plant growth (e.g. toxicities). Within these constraints, the actual amount of organic carbon contained in a soil will be determined by the balance between carbon inputs and losses, which are strongly influenced by land management and soil type. Agricultural practices that alter rates of carbon input (e.g. plant residues, compost, mulch) or loss (e.g. removal of crops, cultivation) change the stock of SOC.

Soil carbon stocks in Australia

At the global scale, the amount of carbon contained in terrestrial vegetation (550 ± 100 petagrams—Pg; 1 Pg is 1 billion tonnes) is of a similar order to that in the atmosphere (800 Pg). However, the organic matter in soils is 2–3 times this amount. Approximately 1500–2000 Pg of carbon is in the top metre of soil, and as much as 2300 Pg is in the top 3 metres. In the Australian continent, the estimated total stock of organic carbon in 2010 in the top 0–30 centimetre layer of soil is 24.97 Pg, with 95 per cent confidence limits of 19.04 and 31.83 Pg (Viscarra Rossel et al. 2014). This represents approximately 3.5 per cent of the total stock in the upper 30 centimetres of soil worldwide. Given that Australia occupies 5.2 per cent of the global land area, the total organic carbon stock of Australian soil is relatively less than in other parts of the world.

SOC stocks are low in many Australian agricultural systems. Conversion from native vegetation to agriculture typically reduces SOC by 20–70 per cent (Luo et al. 2010, Sanderman et al. 2010), and results in declining soil health and significant emissions of greenhouse gases. Conservative forms of land management, such as reduced tillage, stubble retention, green manuring and application of organic amendments, can restore SOC stocks, and have a significant impact on national and global emissions. This opportunity is the motivation behind the '4 per 1000' initiative to increase SOC stocks, which was launched at the UNFCCC Paris meeting, and the Australian Government's Emissions Reduction Fund.

Carbon resilience and land management

There are different types of organic carbon in soils. It is useful to recognise 3 primary fractions (Merry & Janik 2004):

- particulate organic carbon (POC)—organic carbon associated with particles larger than 0.05 millimetres (excluding charcoal carbon)
- humus organic carbon (HUM)—organic carbon associated with particles smaller than 0.05 millimetres (excluding charcoal carbon)
- resistant organic carbon (ROC)—organic carbon found in soil particles smaller than 2 millimetres, having a chemical structure similar to charcoal.

The 3 primary fractions have contrasting dynamics. POC can be readily increased in a soil, but also breaks down quickly. In contrast, ROC takes much longer to increase unless it is added via an amendment such as biochar (charcoal produced from plant matter), which is produced in bushfires.

A review of replicated Australian field trials with timeseries data (Sanderman & Baldock 2010) provided an important insight into carbon dynamics in agricultural systems. It concluded that, although the implementation of more conservative land management practices may lead to a reduced rate of loss of, or indeed a relative gain in, SOC, absolute SOC stocks may still be slowly declining.

Analysis of major management options for sequestering carbon in agricultural soils highlights the trade-off between agricultural production (i.e. carbon exports in the form of crops, fibre and livestock) and carbon sequestration (capture and storage) in soils (Sanderman et al. 2010; Table LAN4).

Assessment of state and trends in carbon across Australia

A group of experts in soil carbon and land resource assessment was convened to provide an assessment of the state and trends in SOC across Australia in 2011. Their assessment summary has been updated, where possible, with more recent state and territory SoE reports, to provide ratings for regions where the most significant issues are apparent (Figure LAN17). The ratings for all physiographic regions are available on the SoE website.

The following conclusions can be drawn from the currently available evidence:

- The time since clearing is a key factor determining current trends. For example, large parts of Queensland are on a declining trend because widespread clearing for agriculture was still occurring in the 1990s.
- Few regions have increasing SOC stores.
- Regions with intensifying systems of land use (e.g. northern Tasmania) have decreasing stores.
- Most regions with a projected drying climate have declining trends.
- The savanna landscapes of northern Australia have significant potential for increasing SOC stores, but this requires changes in grazing pressures and fire regimes (see also Box LAN8).

Some of the extensive cropping lands in southern Australia with weathered and naturally infertile soils are rated as good (i.e. 30–70 per cent loss) or very good (i.e. less than 30 per cent loss) because they had small carbon stores at the time of European occupation and have not changed substantially (although soil biodiversity has undoubtedly changed). Many of these soils have also benefited from the addition of fertiliser and the correction of trace element deficiencies.

In 2009, the Australian Government, with additional investment from the Grains Research and Development Corporation, established the Soil Carbon Research Program, which aimed to:

- assess rapid and cost-effective methodologies for deriving the data required to quantify SOC stocks and composition (allocation to particulate, humus and resistant forms of carbon), and to measure soil bulk density
- develop and implement a nationally consistent approach to quantifying SOC stocks under combinations of major land-use and management regimes, climate, and soil types used for agricultural production in Australia
- quantify the input and subsequent fate of carbon added to soil by agricultural systems based on subtropical perennial pasture species.

Results from the program were published in 2013 in a special issue of the scientific journal *Soil Research* (Box LAN10).

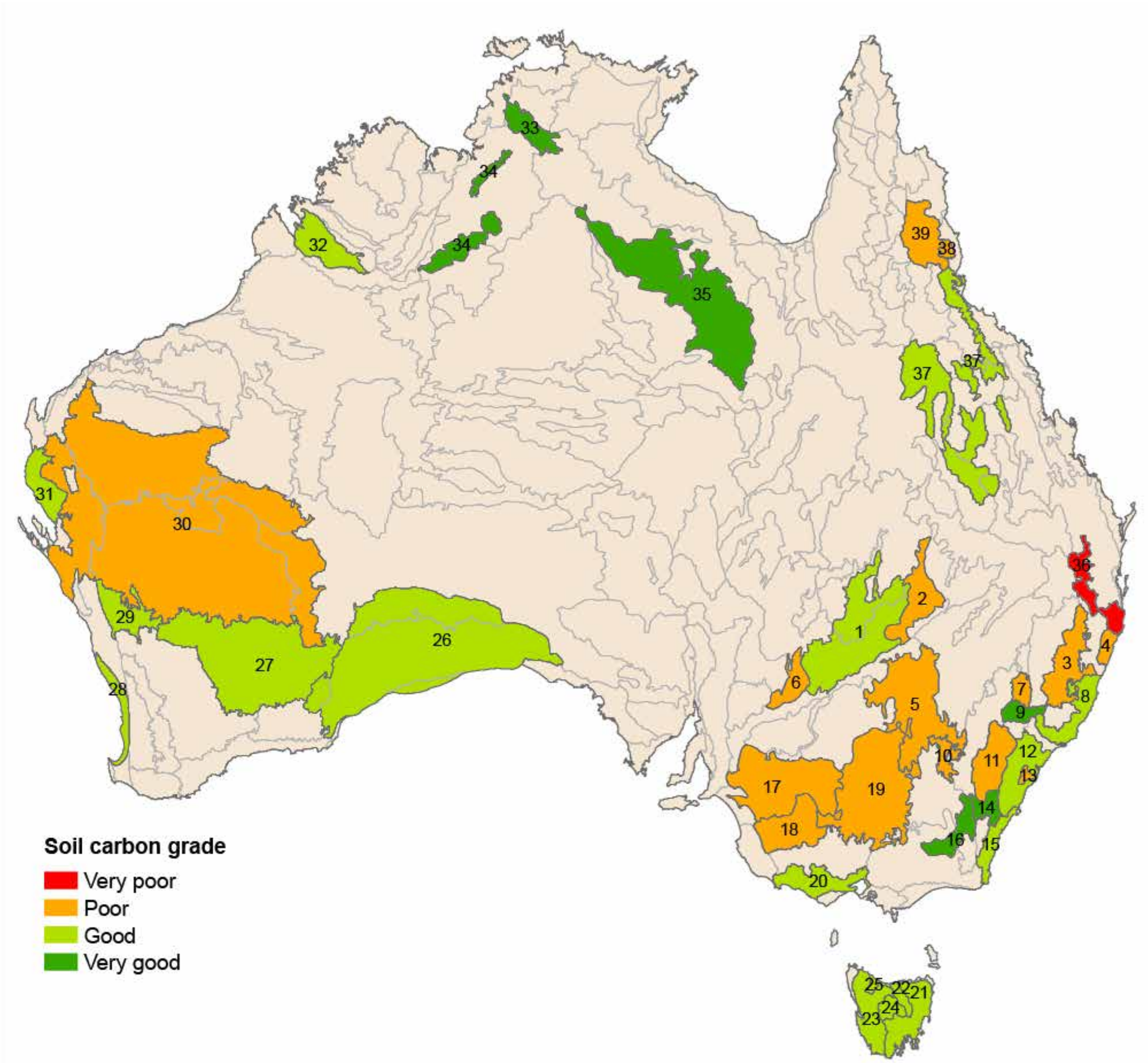
Table LAN4 Summary of major management options for sequestering carbon in agricultural soils

Management	Option	SOC benefit[a]	Confidence[b]	Justification
Shifts within an existing cropping or mixed system	Maximising efficiencies • Water use • Nutrient use	0/+	L	Yield and efficiency increases do not necessarily translate to increased SOC return to soil
	Increased productivity • Irrigation • Fertilisation	0/+	L	Potential trade-off between increased SOC return to soil and increased organic matter decomposition rates Irrigation can increase the rate of soil carbonate precipitation, but, depending on the source of calcium and bicarbonate, the net reaction can be an atmospheric carbon sink, a carbon source or carbon neutrality
	Stubble management • Elimination of burning and grazing	+	M	Greater carbon return to soil should increase SOC stocks
	Tillage • Reduce tillage • Direct drilling	 0 0/+	 M M	Greater organic matter return to soil should increase SOC stocks Reduced till has shown little SOC benefit Direct drilling reduces erosion and destruction of soil structure, thus slowing decomposition rates; however, surface residues decompose with only minor contribution to SOC pool
	Rotation • Elimination of fallow with cover crop • Increased ratio of fallow to crops • Pasture cropping	 + +/++ ++	 M H M	Losses continue during fallow without any new SOC inputs; cover crops mitigate this Pastures generally return more SOC to soil than crops Pasture cropping increases SOC return with the benefits of perennial grasses, such as water use throughout the year and increased below-ground allocation, but studies are lacking
	Organic matter and other offsite additions	++/+++	H	Direct input of SOC (often in a more stable form) into soil; additional stimulation of plant productivity

Table LAN4 (continued)

Management	Option	SOC benefit[a]	Confidence[b]	Justification
Shifts within an existing pastoral system	Increased productivity • Irrigation • Fertilisation	0/+	L	Potential trade-off between increased SOC return to soil and increased organic matter decomposition rates Irrigation can increase the risk of soil carbonate precipitation, but, depending on the source of calcium and bicarbonate, the net reaction can be an atmospheric carbon sink, a carbon source or carbon neutrality
	Rotational grazing	+	L	Increased productivity, including root turnover and incorporation of residues by trampling, but field experience is lacking
	Shift to perennial species	++	M	Plants can use water throughout the year; increased below-ground allocation, but few studies to date
Shift to a different system	Conventional to organic farming system	0/+/++	L	Likely highly variable, depending on the specifics of the organic system (e.g. manuring, cover crops)
	Cropping to pasture system	+/++	H	Annual production minus natural loss is now returned to soil; active management to replant native species often results in large carbon gains

0 = nil; + = low; ++ = moderate; +++ = high; H = high; L = low; M = medium; SOC = soil organic carbon
a Qualitative assessment of the SOC sequestration potential of a given management practice
b Qualitative assessment of the confidence in the estimate of sequestration potential, based on both theoretical and evidentiary lines
Source: Sanderman (2012), Sanderman et al. (2010)



Note: Numbers on the map correspond to the regions listed in assessment summary 4.

Figure LAN17 Rating and condition for soil organic carbon

Box LAN10 Soil Carbon Research Program results

Queensland

- There has been no increase in soil organic carbon (SOC) stocks in response to trash retention and no-till management at 4 sugar cane sites in Queensland, over the top 0.1 or 0.3 metres of the soil profile. Such practices are thus unlikely to lead to significant carbon sequestration for the purpose of greenhouse gas abatement (Page et al. 2014a).
- No-till management, stubble retention and nitrogen fertiliser addition were not able to increase SOC stocks under the climatic conditions found throughout Queensland. To increase SOC stocks in this region, a period of carbon input in the form of a pasture ley is likely to be required (Page et al. 2014b).
- In tropical and subtropical grazing lands, SOC stocks are strongly influenced by temperature, vapour pressure deficit, standing pasture dry matter, soil type and dominant grass species; the effect of grazing management is less clear (Allen et al. 2014).

New South Wales

- Total pre-clearing SOC stocks amounted to 4.21 petagrams (Pg) in the top 30 centimetres, which, compared with a current stock estimate of 3.68 Pg, suggests a total SOC loss of 12.6 per cent over the entire state. The extent of SOC decline in both absolute and relative terms was found to be highly dependent on the climate, parent material and land-use regime, reaching a maximum of 50 per cent relative loss in cooler (moist) conditions over mafic parent materials under regular cropping use (Gray et al. 2016).
- SOC levels in the surface 0.1 metres are 17–28 per cent higher under minimum tillage than under conventional tillage (McLeod et al. 2013).
- No differences in total SOC stock or soil carbon fractions were observed between cropped sites treated with organic amendments and those treated with chemical fertiliser. Relative abundance and microbial community structure, measured on a subset of the cropping sites, showed a higher bacteria:fungi ratio in chemically fertilised sites and suggested enhanced mineralisation of organic matter under conventional management.
- There was some evidence of increased soil carbon stock under rotational compared with continuous grazing, but the difference was not statistically significant (Cowie et al. 2014).
- Sowing perennial tropical grasses improved soil organic matter (including carbon) in the surface 0.1 metre for both cropping and grazing systems (Schwenke et al. 2014).

Victoria

- Across Victoria, SOC content exhibits an extremely wide range (2–239 tonnes of carbon per hectare in the top 30 centimetres). Most of the variation is attributable to differences in climate, annual rainfall or vapour pressure deficit (i.e. humidity). Texture-related soil properties accounted for a small, additional amount of variation in SOC.
- After accounting for climate, differences in SOC between management classes (continuous cropping, crop–pasture rotation, sheep or beef pasture, and dairy pasture) were small and often not significant. Management practices such as stubble retention, minimum cultivation, perennial pasture species, rotational grazing and fertiliser inputs were not significantly related to soil organic carbon stock. Across Victoria, there is a general hierarchy of influence on SOC stock: climate › soil properties › management class › management practices (Robertson et al. 2016).

Tasmania

- Clay-rich soils contained the largest carbon stocks. Cropping sites had 29–35 per cent less SOC in surface soils (0–0.1 metres) than pasture sites, as well as greater bulk densities.
- Rainfall, Australian Soil Classification order and land use were all strong explanatory variables for differences in SOC, soil carbon stock, total nitrogen and bulk density (Cotching et al. 2014).

Box LAN10 (continued)

South Australia

- Differences in SOC between broadscale cropping and crop–pasture systems were limited. In the mid-north, variability in SOC stocks and fractions was high, and could not be explained by environmental or management variables. In the Eyre Peninsula, higher SOC concentrations were observed in the surface 0.1 metre of soils under cropping than under crop–pasture; the particulate organic carbon fraction accounted for most of this SOC and is unlikely to represent a long-term stable pool (Macdonald et al. 2014).

Western Australia

- Although historical losses of soil organic matter associated with agricultural production are significant, soil type, climate and land use influence the potential for SOC storage in Western Australia. Modelling indicates that the greatest storage capacity is below the soil surface (i.e. below 0.1 metres) (Hoyle et al. 2014).

Assessment summary 4

State and trends of soil organic carbon (SOC)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
1 Paroo Plain and Warwick Lowland	Rangelands with extensive grazing and windborne soil erosion, particularly on sandplains. In western New South Wales, 74% of soil monitoring units report SOC reduction as an issue				
2 Warrego Plains	Rangelands with minor opportunity cropping. In western New South Wales, 74% of soil monitoring units report SOC reduction as an issue				
3 Tenterfield Plateau	Grazing of modified and natural pastures, and nature conservation are major land uses. In the Central Plateau of New South Wales, 33% of soil monitoring units report SOC reduction as an issue				
4 Clarence Lowlands	Infertile coastal lowlands used for forestry, grazing, cropping and some nature conservation. In the North Coast region of New South Wales, 56% of soil monitoring units report SOC reduction as an issue				
5 Cobar Plains	Historically poor management has depleted SOC. Overgrazing by feral goats is causing further decline, despite improving land management. In western New South Wales, 74% of soil monitoring units report SOC reduction as an issue				
6 Barrier Ranges	Surface SOC is low as a result of grazing and prior clearing. In the Central Tablelands region of New South Wales, 40% of soil monitoring units report SOC reduction as an issue				

Assessment summary 4 (continued)

Component	Summary	Assessment grade: Very poor	Assessment grade: Poor	Assessment grade: Good	Assessment grade: Very good	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
7 Gunnedah Lowlands	Declining trend due to intensification of cropping. In the north-west region of New South Wales, 18% of soil monitoring units report SOC reduction as an issue		?					
8 Macleay Barrington Fall	Area is used for nature conservation and production forestry, with some grazing. Possible decline in SOC due to logging. In the Hunter region of New South Wales, 50% of soil monitoring units report SOC reduction as an issue			?				
9 Merriwa Plateau	Mixed farming on naturally fertile Ferrosols and Vertosols. In the Hunter region of New South Wales, 50% of soil monitoring units report SOC reduction as an issue				?			
10 Condobolin Plains	Soils are Sodosols and Vertosols, used for cropping and grazing. In the Central West region of New South Wales, 19% of soil monitoring units report SOC reduction as an issue		?					
11 Bathurst Tablelands	Grazing of modified and natural pastures dominates. In the Central Tablelands region of New South Wales, 40% of soil monitoring units report SOC reduction as an issue		?					
12 Hawkesbury Shoalhaven Plateaus	Diverse landscape with natural conservation, forestry, grazing, horticulture and urban land uses. Fire regime and land management practices are most likely causing a decline in SOC. In the Greater Sydney region of New South Wales, 57% of soil monitoring units report SOC reduction as an issue			↙				
13 Cumberland Lowland	Mostly urban and industrial land use. In the Greater Sydney region of New South Wales, 57% of soil monitoring units report SOC reduction as an issue		?					

Assessment summary 4 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
14 Werriwa Tablelands	In the South East region of New South Wales, 59% of soil monitoring units report SOC reduction as an issue. No data from the Australian Capital Territory	Good ↙	¾	¾	
15 Monaro Fall	Good levels of SOC under nature conservation, forestry and grazing. Land management is improving	Good ?	¾	¾	
16 Australian Alps	Mostly used for nature conservation. Controls on grazing and reduced erosion stabilised early losses, but the increased intensity and extent of fires are likely to be causing a decrease, particularly in Organosols	Very good ?	¾	¾	
17 Mallee Dunefield	Cropping, grazing and nature conservation with irrigated agriculture along the Murray River. Improved farming practices have improved soil condition in some areas	Poor ?	¾	¾	
18 Wimmera Plain	Mainly cropping and grazing. Former grazing lands now used for nature conservation may still be experiencing declining carbon content. Changing farming practices to no-till may be increasing soil organic carbon content in some areas, especially on heavier soils	Poor ?	¾	¾	
19 Riverine Plains	Dryland cropping and irrigated agriculture, with grazing in the west. None of the soil monitoring units in the Riverina region of New South Wales reported SOC as an issue	Poor ?	¾	¾	
20 West Victorian Plains	Grazing, cropping and expanding plantation forestry. Areas converted from pasture to cropland are probably declining, as are soils used for continuous cropping	Good ?	¼	empty	

Assessment summary 4 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
21 Midlands Plain	Dryland cropping, grazing and increasing irrigated cropping. Intensification of cropping is probably causing a decline in SOC	?			
22 Lakes Plateau	Nature conservation reserves. Where wildfire and grazing have resulted in sheet erosion over large areas, SOC has been lost, with limited potential for recovery	?			
23 West Tasmanian Ridges	More frequent and/or hotter fires in conservation reserves are causing losses, especially in Organosols. Production forestry in the north suggests little potential for increase in SOC sequestration	?			
24 East Tasmanian Hills	Production and plantation forestry, with minor decline due to erosion. Irrigated cropping in the south-east and north-east is causing a decline in SOC	?			
25 North West Ramp	Decline in SOC is associated with irrigated cropping	?			
26 Roe and Carlisle Plains, Coonana–Ragged and Bunda Plateaus	Mainly grazing of native vegetation. Shift from perennials to annuals and possible increase in fire frequency may lead to decline in SOC	?			
27 Southern Goldfields Plateau	SOC decline is restricted to pastoral areas	?			
28 Swan Plain	Urban areas and intensive agriculture. High levels of SOC are often associated with irrigated pasture. Decline in SOC is likely under intensive horticultural systems	?			

Assessment summary 4 (continued)

Component	Summary	Assessment grade: Very poor	Poor	Good	Very good	Confidence: In grade	In trend	Comparability: To 2011 assessment
29 Woodramung Hills	Low-input cropping and grazing. Drying trends have compounded effects of clearing and cropping on SOC loss			?		◓	○	⬙
30 Murchison Plateau, Leemans and Yaringa Sandplains, Carnegie and Glengarry Hills, Augustus Ranges	Areas with extensive grazing of native vegetation, with declines in SOC in more heavily grazed areas. Few data in driest areas		?			◔	○	⬙
31 Carnarvon Plain	Nature conservation, extensive grazing; small areas of intensive irrigated horticulture are likely to have a decline in SOC			?		◔	○	⬙
32 Fitzroy Plains	Extensive grazing of native vegetation			?		◔	○	⬙
33 Daly Basin	Small areas of intensive agriculture are likely to have declining SOC. Remainder is used for extensive grazing				?	◔	○	⬙
34 Whirlwind Plain and Birrundudu Plain	Extensive grazing, with small areas of more intensive development on better soils. Possible minor decreases in SOC due to high seasonal stocking rates				?	◔	○	⬙
35 Barkly Tablelands	Extensive grazing on clay plains, with decline in SOC likely				?	◔	○	⬙
36 Toowoomba Plateau	Ferrosols used for cropping and pasture, with increasing agroforestry. Slow recovery after large historical loss of SOC	?				◔	○	⬙
37 Central Uplands	Partially cleared grazing country. SOC is likely to be declining in recently cleared areas; otherwise stable			?		◔	○	⬙

Assessment summary 4 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
38 Atherton Tableland	Fertile land with high rainfall. Diverse land uses, with SOC now recovering under pastures and tree crops; it is likely still decreasing under small-grain and horticultural crops	Poor ?	Very limited	Low	Somewhat comparable
39 Garnet Uplands	Recently intensified land use after clearing; therefore, SOC is likely declining	Poor ?	Very limited	Low	Somewhat comparable

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Grades

- **Very good:** Carbon stocks have either remained the same or increased (<30% loss or increase)
- **Good:** Carbon stocks have changed in some areas (30–50% loss)
- **Poor:** Carbon stocks have decreased (50–70% loss)
- **Very poor:** Carbon stocks have decreased substantially (>70% loss)

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Soil salinity

Secondary dryland salinity has been one of Australia's most costly forms of land degradation. Most annual crops, such as wheat, are susceptible to salinity, which reduces grain yields if it exceeds a threshold level. The assessment completed by the National Land & Water Resources Audit (NLWRA) in 2001 (NLWRA 2001) is still the most comprehensive overview of dryland salinity in Australia. Assuming no changes in water balance, the NLWRA expected dryland salinity to increase from 5.7 million hectares to 17 million hectares by 2050. However, the millennium drought appears to have halted the spread of dryland salinity in most of the worst-affected regions, especially in south-western Western Australia and Victoria; the spread is likely to increase with a return to wetter conditions. Large areas of New South Wales along the Great Dividing Range, and in the Liverpool Plains, Hunter Valley and Greater Sydney regions reported soil salinity as their main issue of concern (NSW EPA 2015).

The outlook described by the NLWRA will need further consideration if current projections for a drying of southern Australia are correct. However, the long-term outlook for more recently cleared land in the northern Murray–Darling Basin and central Queensland is unclear. Large areas are yet to reach a new hydrological equilibrium after clearing.

Given the effects of drought over the past decade, this report does not provide an update on previous SoE reports or the NLWRA assessment regarding salinity. However, close surveillance of groundwater systems is essential, particularly in regions that returned to wetter conditions in 2010–15. A key requirement for understanding the state of dryland salinity in Australia will be to maintain the groundwater monitoring network established under the National Action Plan for Salinity and Water Quality.

Soil acidification

Soil acidification is an insidious process that develops slowly. If not corrected, it can continue until the soil is irreparably damaged. Acidification affects about half of Australia's agriculturally productive soils.

Soil acidification is of greatest concern in situations where:

- agricultural practices increase soil acidity (e.g. use of high-ammonium nitrogen fertilisers, large rates of product removal)
- the soil has a low capacity to buffer the decrease in pH (e.g. infertile, light-textured soils)
- the soil already has a low pH.

The process of acidification considered in this report is distinct from that associated with acid sulfate soils. Such soils occur primarily in coastal settings and naturally contain iron sulfide, which causes severe acidification when it oxidises. This can occur through drainage of coastal wetlands or exposure due to drought, as was the case in the Lower Lakes of South Australia during the millennium drought.

The main onsite effects of acidification include:

- loss of, or changes in, soil biota involved in nitrification (which fix nitrogen, a key nutrient, within the soil)
- accelerated leaching of plant nutrients (manganese, calcium, magnesium, potassium and anions)
- induced nutrient deficiencies or toxicities
- breakdown and subsequent loss of clay materials from the soil
- development of subsoil acidity
- reduced net primary productivity and carbon sequestration
- erosion as a result of decreased groundcover that may follow acidification.

The potential offsite effects include:

- mobilisation of heavy metals into water resources and the food chain
- acidification of waterways as a result of leaching of acidic ions
- increased siltation (where fine sediments suspended in the water are deposited on the floor) and eutrophication (where a high concentration of nutrients typically triggers excess growth of algae) of streams and water bodies.

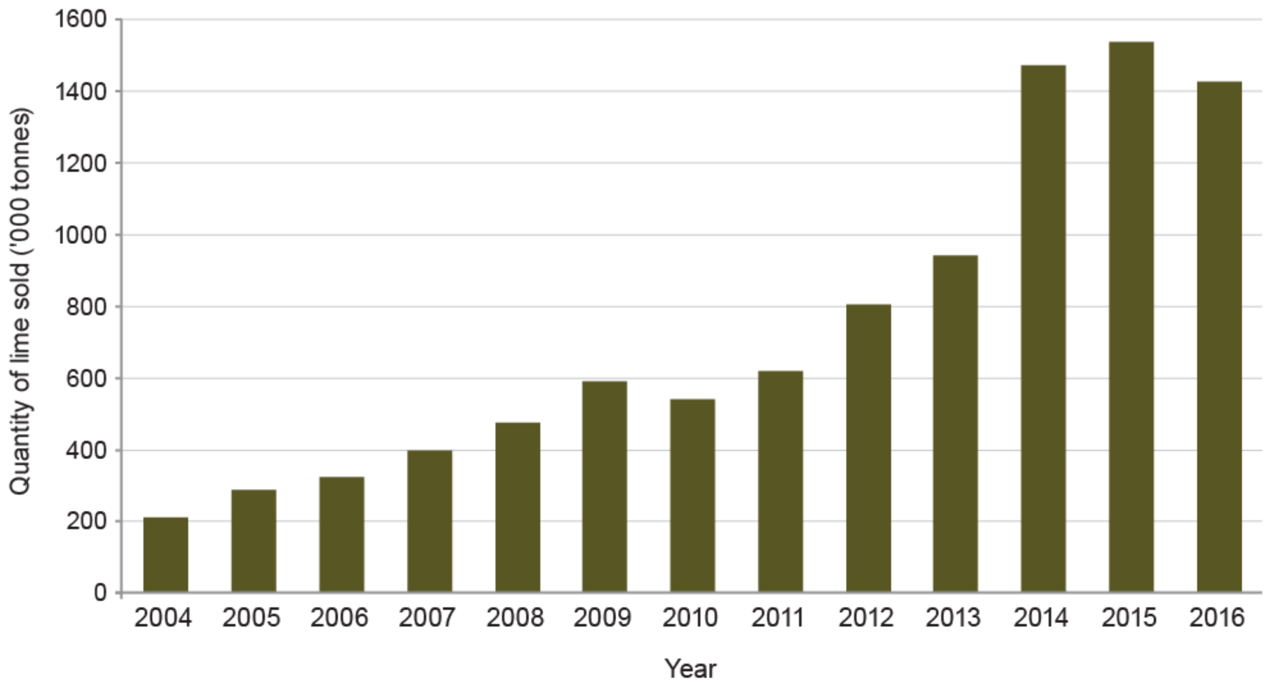
Soil acidification in Australia

Soil acidity affects approximately 50 million hectares (50 per cent of Australia's agricultural land) and about 23 million hectares of subsoil layers, mostly in Western Australia and New South Wales (NLWRA 2001).

Soil acidification restricts options for land management, because it limits the choice of crops and vegetation to acid-tolerant species and varieties. It is relatively straightforward to reverse short-term surface soil acidification through the application of lime. However, it is much harder to reverse the problem if the acidification has advanced deeper into the soil profile, because incorporating lime at depth is more expensive.

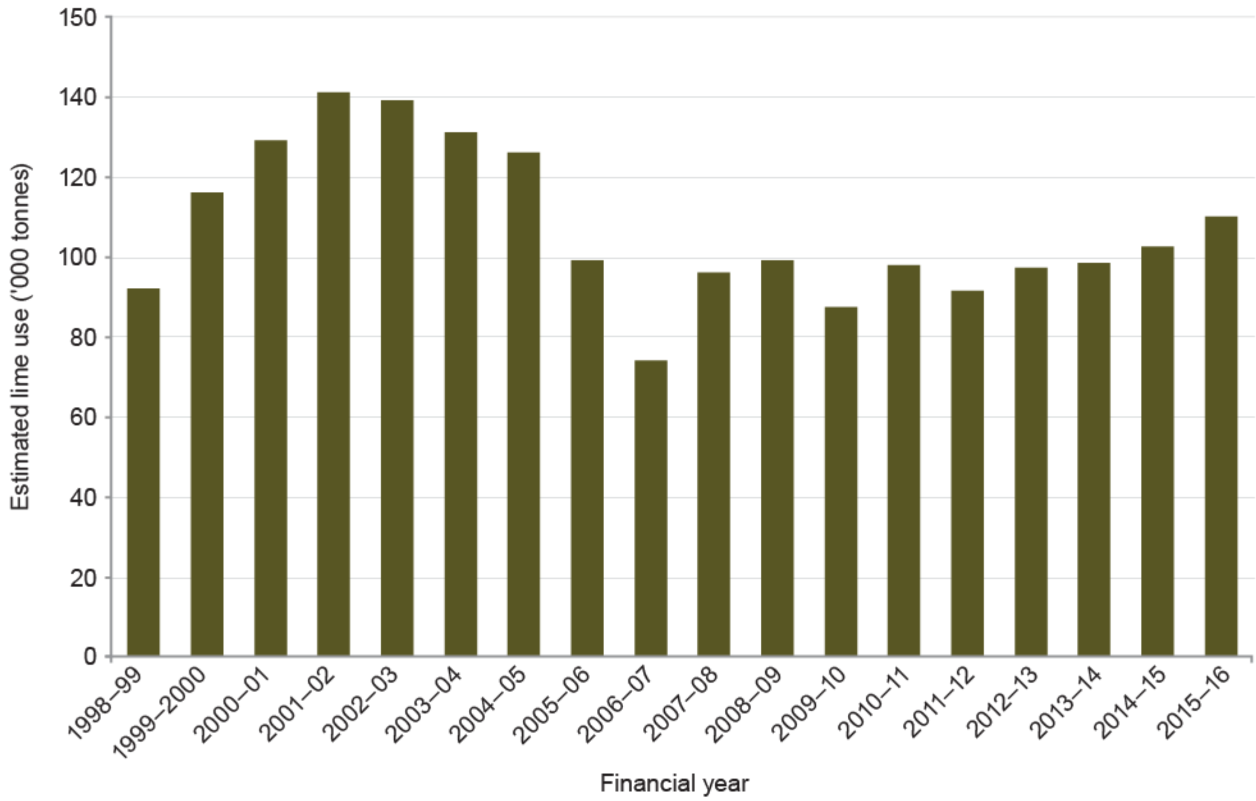
Although rates of lime application appear to be increasing, they still fall far short of what is needed to ameliorate existing, and counter ongoing, soil acidification. Western Australia, where more than 70 per cent of surface soils are below appropriate pH levels, has one of the best programs in Australia for combating acidification, but the rates of lime application are still much lower than what is needed to avoid irreparable damage (Gazey et al. 2013; Figure LAN18).

A similar situation exists in South Australia (Figure LAN19). The average quantity of lime sold annually during the past decade is just under half the amount required to balance the estimated annual soil acidification rate (South Australian Government 2013a).



Source: Lime WA Incorporated

Figure LAN18 Estimated lime application in Western Australia to treat acidifying soils, 2004–16



Source: Department of Environment, Water and Natural Resources, South Australia

Figure LAN19 Estimated lime application on agricultural land in South Australia, 1998–2016

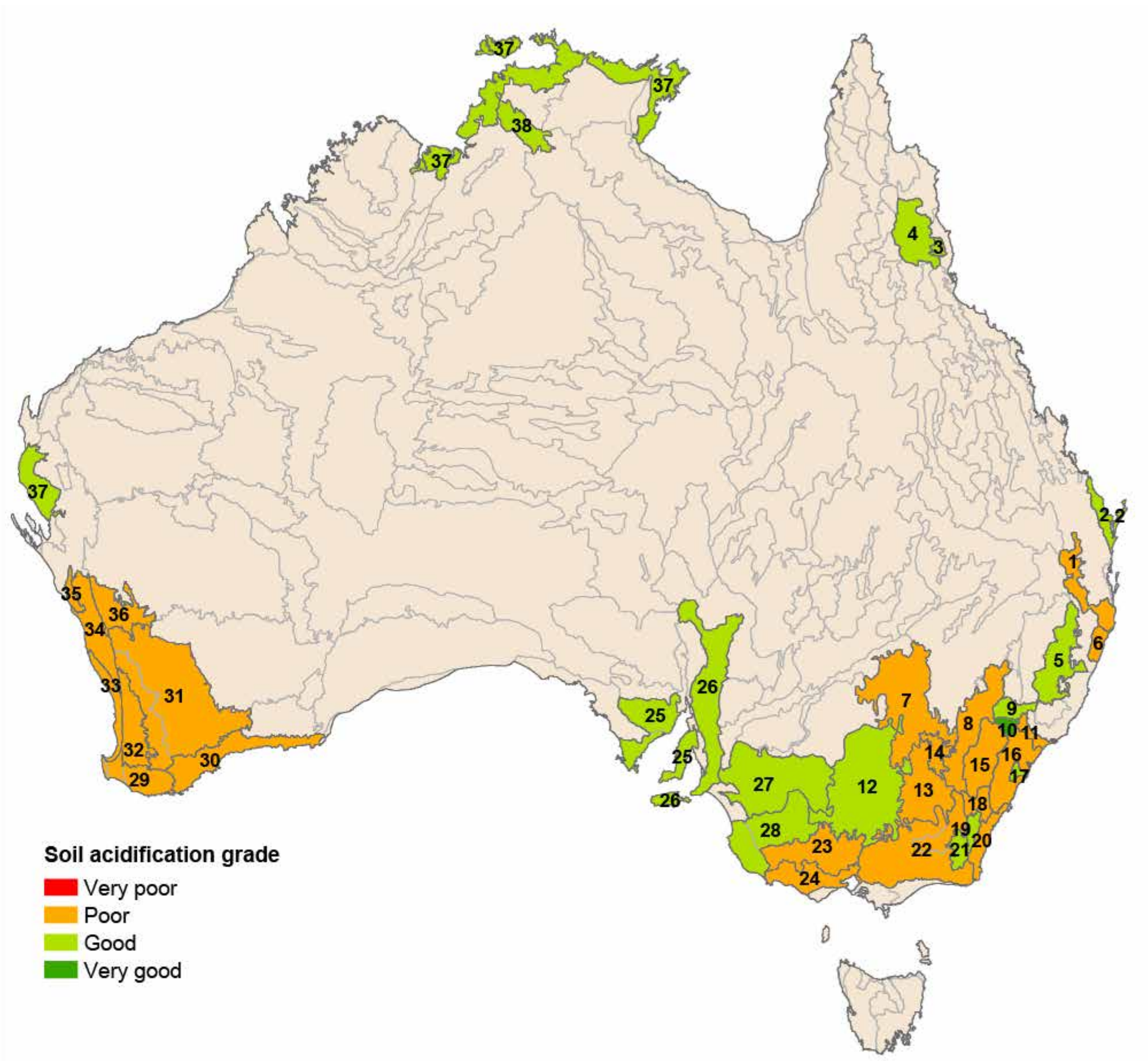
Assessment of state and trends of soil acidification in Australia

In 2011, a group of experts in soil acidification and land resource assessment was convened to provide an assessment of the state and trends of soil acidification across Australia. This assessment has been updated using more recent state and territory SoE reports, where available (Figure LAN20). The assessment summary provides ratings for regions where the most significant issues are apparent. The ratings for all physiographic regions are available on the SoE website.

Only some states (Western Australia, New South Wales and South Australia) have some form of organised monitoring system for soil acidification, which accounts for the significant uncertainty in many regions.

The current assessment is as follows:

- Soil acidification is widespread in the extensive farming lands of southern Australia.
- Rates of lime application are well short of the rates needed to arrest the problem.
- Acidification is common in intensive systems of land use (tropical horticulture, sugar cane, dairying).
- Acidification is limiting biomass production in some regions, but the degree of restriction is difficult to estimate.
- Trends in the tropical savannas are uncertain. If acidification is occurring, it will be a difficult problem to solve.
- Carbon losses are most likely occurring across regions in poor condition, and soil acidification is a major constraint on storing carbon in soils in the future.



Note: Numbers on the map correspond to the regions listed in assessment summary 5.
Source: State of the environment reports from states and territories

Figure LAN20 Rating and condition for soil acidity

Assessment summary 5

State and trends of soil acidification

Component	Summary	Assessment grade: Very poor	Poor	Good	Very good	Confidence: In grade	In trend	Comparability: To 2011 assessment
1 Toowoomba Plateau	Naturally fertile land under intensive use. Insufficient lime application		?					
2 Maryborough Lowland	Soils under pine plantations are acidifying, but improved practices for sugar cane and horticulture appear to be effective		?					
3 Atherton Tableland	Improved practices across diverse land uses, but localised subsoil acidification under banana cropping			?				
4 Garnet Uplands	Recently intensified land use after clearing			?				
5 Tenterfield Plateau	Grazing of modified and natural pastures, with widespread declines in pH. In the Northern Tablelands region of New South Wales, 11% of soil monitoring units report acidification as an issue			?				
6 Clarence Lowlands	Coastal lowlands with a variety of soil types. Significant decline in pH on the floodplains due to intensive agriculture. In the North Coast region of New South Wales, 22% of soil monitoring units report acidification as an issue		?					
7 Cobar Plains	Cropping and grazing of modified and natural pastures in the east, with declines in pH evident		?					
8 Mitchell Slopes	Diverse landscape, but pH has declined markedly, especially on soils with a long history of mixed farming		?					

Assessment summary 5 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
9 Merriwa Plateau	Fertile Ferrosols and Vertosols, mostly used for mixed farming. Slow decline in pH likely due to management systems	↙			
10 Goulburn Corridor	Minimal evidence, but declines in pH are expected as a result of lack of liming	?			
11 Hunter Valley	Soil acidity is a problem on coastal floodplains. In the Hunter region of New South Wales, 25% of soil monitoring units report it as an issue	?			
12 Riverine Plain	Diverse region, with probable decline in pH in irrigation districts, and in soils used for dryland cropping and grazing of annual pastures, especially in the south. None of the soil monitoring units in this region have reported soil acidity as an issue	?			
13 Hume Slopes	Mostly mixed farming. Widespread and significant declines in soil pH. In the South East region of New South Wales, 18% of soil monitoring units have reported soil acidity as an issue	?			
14 Condobolin Plains	Declines in pH restricted to irrigation districts	?			
15 Bathurst Tablelands	Diverse soils, used for grazing of modified and natural pastures. None of the soil monitoring units in the Central Tablelands region of New South Wales have reported soil acidity as an issue	?			

Assessment summary 5 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
16 Hawkesbury Shoalhaven Plateau	Substantial declines in pH in soils used for agriculture. In the Greater Sydney region of New South Wales, 43% of soil monitoring units have reported soil acidity as an issue	Poor ?			
17 Cumberland Lowland	Declining pH in soils used for vegetable production and intensive agriculture	Good ↙			
18 Werriwa Tablelands	Declining pH in soils used for grazing of native and improved pastures	Poor ?			
19 Tinderry–Gourock Ranges	Declining pH in soils used for grazing of natural and modified pastures	Good ?			
20 Monaro Fall	Declines in pH in soils used for grazing	Poor ?			
21 Monaro Tableland	Declining pH in soils used for grazing of natural and modified pastures	Good ?			
22 Australian Alps and East Victorian Uplands	Grazing lands outside conservation reserves are showing declines in pH	Poor ?			
23 West Victorian Uplands	Areas used for grazing of dryland annual pastures are acidifying	Poor ?			
24 West Victorian Plains	Diverse lands, with evidence of acidification on poorly drained Sodosols and Vertosols used for dryland cropping and grazing of annual pastures	Good ?			
25 Lincoln Hills, Eyre Dunefield and Yorke Peninsula	Mainly dryland agriculture. Generally stable pH in Calcarosols, but rates of liming are not sufficient to balance rates of acid addition for most soils	Good ↙			

Assessment summary 5 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
26 Flinders–Lofty Ranges	Diverse lands, with stable pH in the arid north. Declines in pH are occurring in the temperate central area under dryland cropping and viticulture, and in the cool temperate south under viticulture, horticulture and grazing	Good —	●	●	◆
27 Mallee Dunefield	Mainly cropping in rotation with pastures. Declining pH in surface soil over calcareous subsoils. Significant declines in pH in horticulture areas along the Murray River	Good ↗	●	●	◆
28 Wimmera and Millicent Plains	Diverse soils, used for dryland cropping, grazing, some irrigation, and forestry in the south. Declining trend in pH due to insufficient lime use	Good —	●	●	◆
29 Warren–Denmark Slopes, Leeuwin Peninsula and Donnybrook Lowland	Forestry, intensive agriculture and dryland cropping. Intensively used areas are still below desired pH	Poor ↙	●	●	◆
30 Albany Esperance Sandplain	Grazing and cropping systems are acidifying, particularly on lighter soils	Poor ↙	●	●	◆
31 Avon Plateau and Northam Slopes	Diverse soils. Widespread surface and subsurface soil acidity. Some improvement in the north	Poor ↙	●	●	◆

Assessment summary 5 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
32 Darling Range	Mostly forested, but areas used for cropping and grazing are acidifying	Poor, Deteriorating	Adequate	Adequate	Comparable
33 Swan Plain	Urban areas and intensive agriculture. Most of the region is below desired pH and continues to acidify	Poor, Deteriorating	Adequate	Adequate	Comparable
34 Dandaragan Tablelands	Some local pockets of improvement in pH trend, but decline in pH continues	Poor, Stable	Adequate	Adequate	Comparable
35 Greenough Hills	Some local pockets of improvement in pH trend, but decline in pH continues	Poor, Improving	Adequate	Adequate	Somewhat comparable
36 Woodramung Hills	Some local pockets of improvement in pH trend, but decline in pH continues	Poor, Deteriorating	Adequate	Adequate	Comparable
37 Carnarvon and Top End Coastal Plains	Probable declining pH in agricultural areas used for intensive irrigation and horticulture	Good, Deteriorating	Very limited	Very limited	X (Not previously assessed)
38 Daly Basin	Probable declining pH in areas used for horticulture and more intensive pastoral development	Good, Unclear	Very limited	Low	Somewhat comparable

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very good:** Current management is adequate, and a low level of monitoring is required
- **Good:** Needs management and monitoring, otherwise returns will be threatened
- **Poor:** Urgent amelioration is needed. Yields and returns are compromised, and returns are currently threatened
- **Very poor:** Beyond economic recovery; yields are no longer economic. Current system is untenable, with limited options

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Soil formation and erosion

Under steady state, erosion rates are equal to soil formation rates.

The fastest rates of soil formation occur in dune sands in moist environments, where weakly developed soils can develop over decades or centuries. For example, in the Macquarie River, alluvium soils classified as Dermosols, Rudosols and Vertosols (see Table LAN3) have formed in less than 5000 years.

Soil formation from weathering rock is slower, and varies with the environment and rock type. An average of about 10 millimetres per 1000 years is typical in New South Wales, increasing to about 75 millimetres per 1000 years in Arnhem Land, Northern Territory. These soil formation rates are low compared with the estimated global average of 114 millimetres per 1000 years (Stockmann et al. 2014).

In Victoria, soil erosion declined between 1990 and 2010, probably as a consequence of the widespread adoption of soil conservation measures during the previous 30 years (Chappell et al. 2012). Similarly, in South Australia, soil protection increased between 2003 and 2013 in parallel with the increasing adoption of no-till methods (South Australian Government 2013b).

Water erosion

Current rates of soil erosion by water across much of Australia now exceed soil formation rates by an order of magnitude or more. As a result, the expected half-life of soils (the time for half the soil to be eroded) in some upland areas used for agriculture has declined to merely decades.

The latest assessment (Bui et al. 2010) concluded that soil erosion by water in Australian cropping regions is still at unsustainable rates, but there are large uncertainties about the time until soil loss will have a critical impact on agricultural productivity. Environmental impacts of excessive sedimentation and nutrient delivery on inland waters, estuaries and coasts are already occurring.

Up to 10 million hectares of land have less than 500 years until the soil's A horizon (the more fertile 'topsoil') will be lost to erosion. Most of this land is in humid, subtropical Queensland.

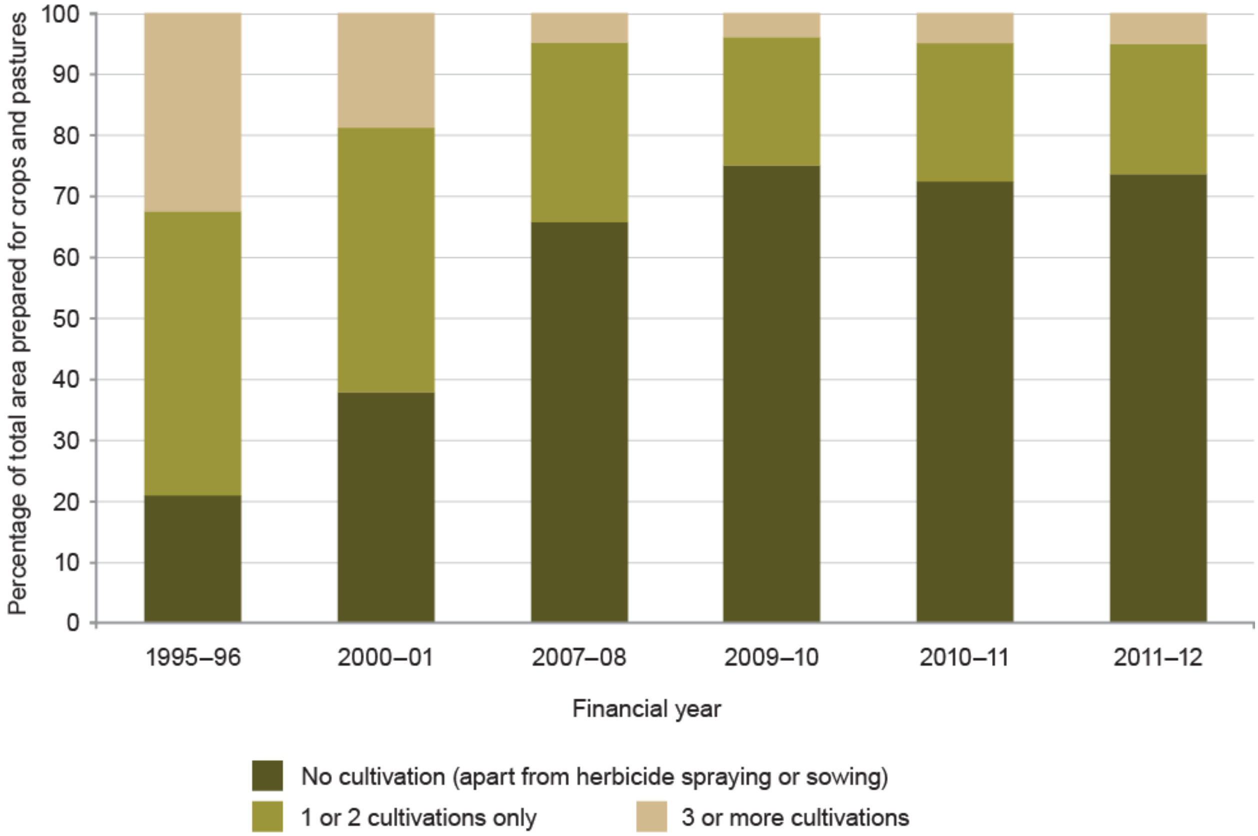
A recent study (Bartley et al. 2015) compared long-term (between 100 and more than 10,000 years) erosion rates with contemporary erosion rates obtained by monitoring sediment fluxes over about 5–10 years in Queensland's Burdekin River Basin. The ratio of these 2 erosion rates provides a measure of the accelerated erosion factor (AEF), which can be used to identify erosion hotspots and prioritise investment in land remediation at the subcatchment scale. All but 2 of the Burdekin subcatchments had an AEF greater than 1.0, indicating higher contemporary erosion rates than estimated long-term averages. Within the context of the Reef Water Quality Protection Plan, these results justify the setting of water quality targets at the subcatchment scale. More integrated studies of soil formation and erosion using a variety of techniques will be needed to better understand the extent, severity and significance of the problem. However, it is clear that a concerted program of soil conservation is essential to control this chronic form of land degradation across large areas of Australia.

The key to controlling soil erosion by water is maintenance of a protective cover (e.g. living plants, litter, mulch) on the soil surface. Other soil conservation practices—such as contour banks, filter strips and controlled traffic—are important, but secondary to the maintenance of cover.

Land management practices have improved significantly during the past few decades, as a result of better grazing practices, adoption of conservation tillage, enforcement of forestry codes and soil conservation measures in engineering (e.g. relating to road construction and urban development).

The ability to monitor land cover provides a key input to assessments of erosion risk across the landscape (Yang 2014). Remotely sensed monitoring of land cover and land use is now routinely used to identify trends (Guerschman et al. 2009, Malthus et al. 2013). Together with data on land management practices available from the Australian Bureau of Statistics, these trends reveal:

- a pattern of more careful grazing and maintenance of effective land cover at critical times of the year
- improved adoption of conservation practices, especially across the cropping lands of southern Australia
- an associated large decline in the amount of tillage in farming systems (Figure LAN21).

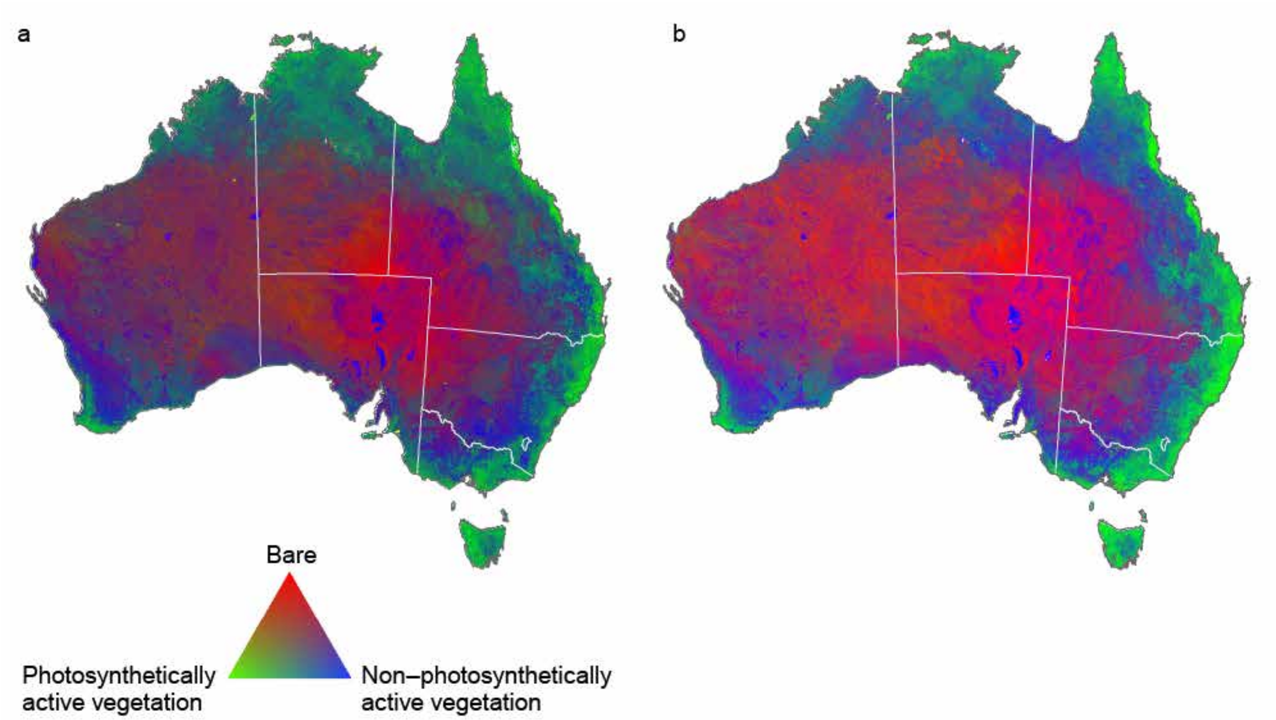


Source: Australian Government Department of Agriculture and Water Resources, using data from the Australian Bureau of Statistics (specifically the 2007–08, 2009–10 and 2011–12 Agricultural Resource Management Survey, and the 1995–96, 2000–01 and 2010–11 Agricultural Census, customised by commodity groupings)

Figure LAN21 Change in the percentage area of all land prepared for crops and pastures under different tillage practices, 1995–2012

Figure LAN22 shows 2 images of Australia derived from remotely sensed data. The images show the proportion of bare soil and surface cover that is either photosynthetically active (i.e. growing vegetation) or inactive (e.g. crop residues, plant litter).

Figure LAN22a shows the Australian continent in 2006, during the millennium drought. Figure LAN22b shows the same seasonal period in 2015, after the drought had broken in 2010–11. Reductions in the area of bare soil are evident in the Central Lowlands Province, and the east and south-east of the continent. The intense rainfall and floods associated with the breaking of the drought resulted in widespread erosion, especially in south-east Queensland. A complete timeseries showing monthly images for the past 15 years is available on the SoE website, illustrating the pervasive effect of fire, especially across northern Australia.



Source: The data underpinning this figure were obtained through TERN AusCover. TERN is Australia's land-based ecosystem observatory, delivering data streams to enable environmental research and management. TERN is a part of Australia's National Collaborative Research Infrastructure Strategy.

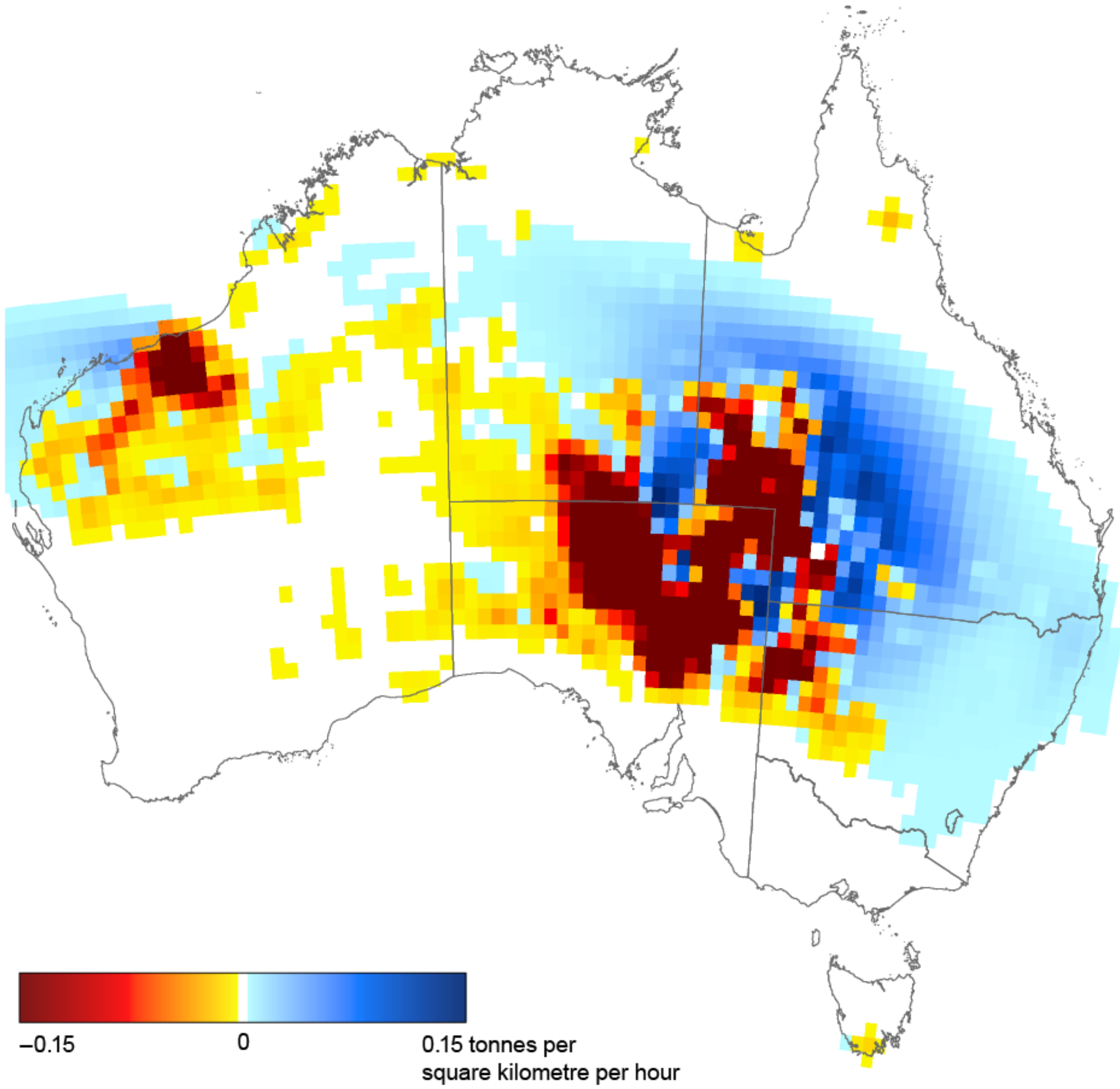
Figure LAN22 Images of Australia derived from remotely sensed data, showing the proportion of bare soil, photosynthetically active vegetation and non–photosynthetically active vegetation for April in (a) 2006 and (b) 2015

Wind erosion

Climate is by far the strongest determinant of wind erosion: soil that is wet or covered by vegetation does not get blown away by the wind. Land management can thus either reduce or increase wind erosion rates. Unravelling of the respective influences of climate and land management was made easier by the impacts of the millennium drought, which allowed comparisons between past and current management approaches, and of the effectiveness of different approaches to land management.

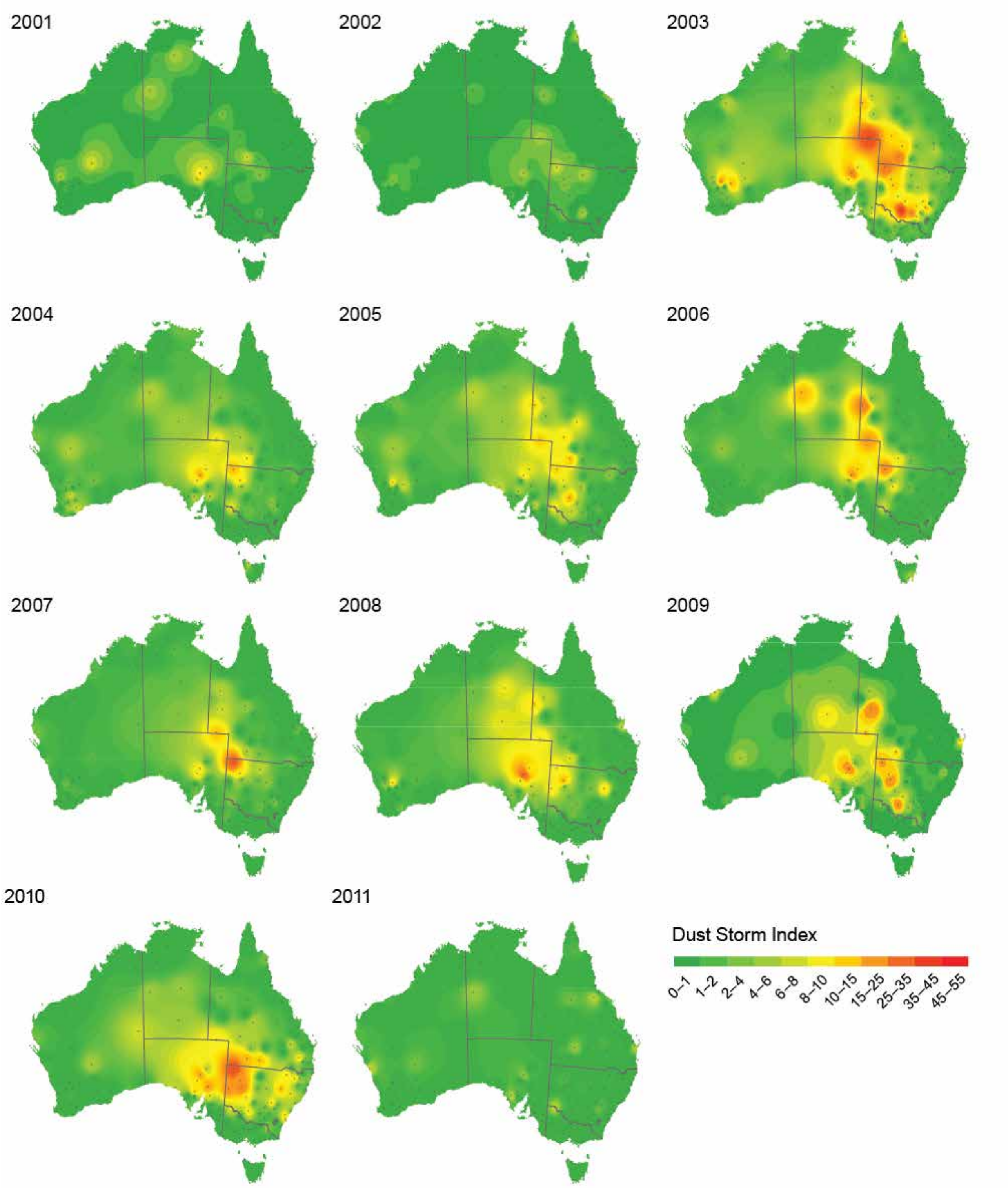
The millennium drought resulted in large dust storms and other wind erosion activity. Two extreme dust storms hit eastern Australian cities on 23 October 2002 and 23 September 2009. The origin of large amounts of windborne soil—in South Australia, northern New South Wales, and central and western Queensland—and the sites of deposition to the north and east, are shown in Figure LAN23. Wind erosion has environmental impacts at the source, where soils are eroded (onsite wind erosion), and much greater economic and human health impacts downwind from the source, where air quality is reduced (offsite wind erosion). These extreme dust storms increased public awareness of both these types of impact.

Compilations of dust storm activity year by year (Figure LAN24) show that, although the sites of origin may be similar, annual climatic variation has an immense impact on the magnitude of wind erosion.



Source: Dustwatch Australia, as published in Butler et al. (2013)

Figure LAN23 Estimated net soil loss due to wind erosion, 22–23 September 2009

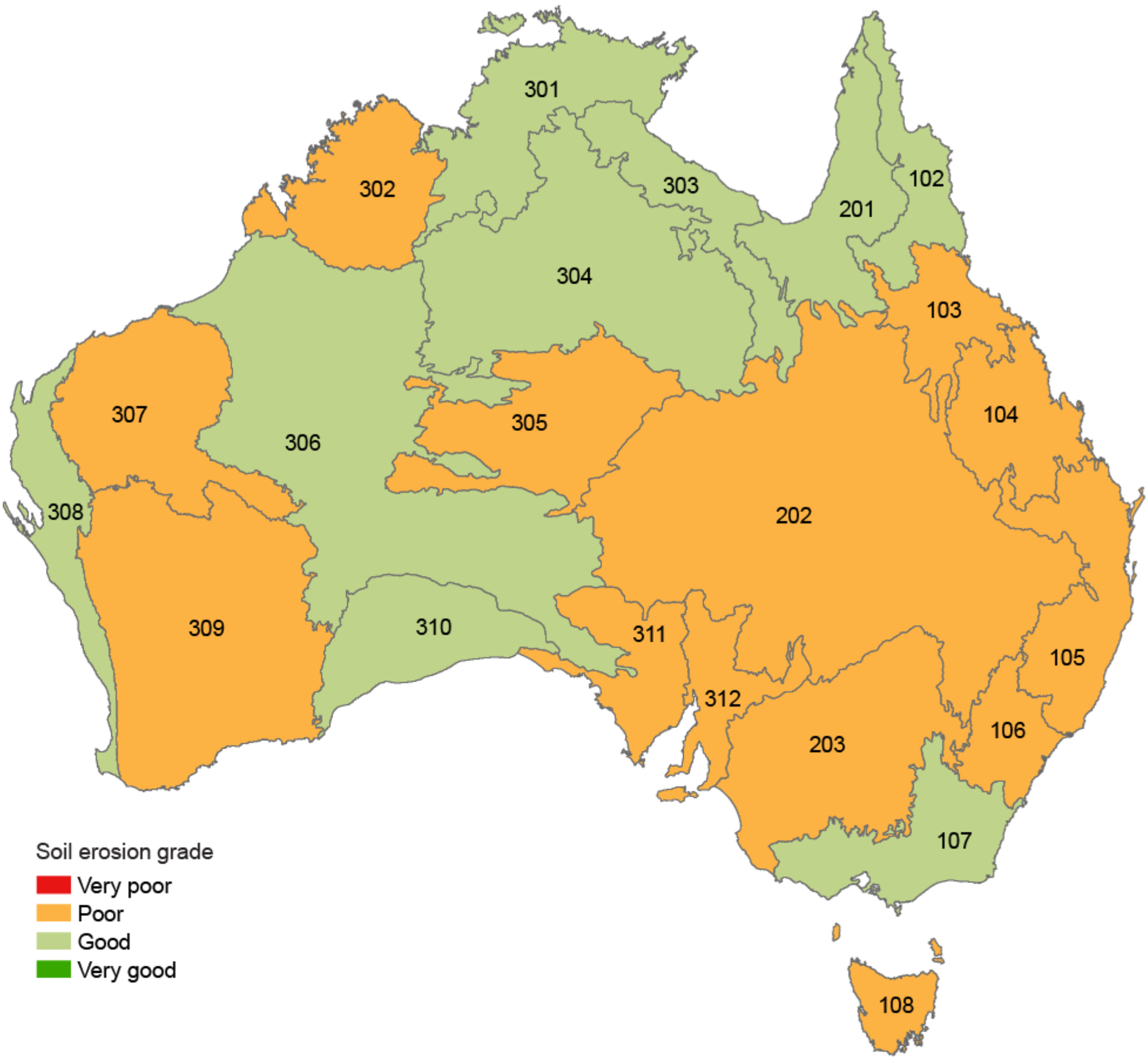


Source: Dustwatch Australia, as published (for years 2001–09) in McTainsh et al. (2011)

Figure LAN24 Dust storm activity across Australia based on 356 stations, 2001–11

Assessment of state and trends of soil erosion across Australia

Figure LAN25 and assessment summary 6 provide an assessment of soil erosion by wind and water across Australia. The assessment draws from the SoE reports for Western Australia, South Australia and New South Wales (NLWRA 2003, Bastin & the ACRIS Management Committee 2008, Bui et al. 2010, McTainsh et al. 2011, Chappell et al. 2012, Butler et al. 2013, Bartley et al. 2015, Teng et al. 2016).



Note: Numbers on the map correspond to the regions listed in assessment summary 6.

Figure LAN25 Grade of soil erosion for the physiographic provinces of Australia

Sugar cane landscape with drainage ditch and cattle egrets, Dallachy, Queensland
Photo by Dan Metcalfe, CSIRO

Assessment summary 6

State and trends of soil erosion by water and wind

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
102 Peninsular Province	Land management in the grazing and cropping lands is improving, although localised waterborne erosion continues	?			
103, 104 Burdekin and Fitzroy Provinces	Erosion continues to be a problem that threatens water quality and the Great Barrier Reef, although land management in the grazing and cropping lands is improving	↗			
105, 106 New England—Moreton and Macquarie Uplands Provinces	In the North Coast region of New South Wales, 80% of soil monitoring units report sheet erosion as an issue; 20% also report gully erosion as a problem	—			
107 Kosciuszkan Uplands Province	Good, but 79% of soil monitoring units in the South East region of NSW report sheet erosion as an issue; 9% also report gully erosion as a problem	↙			
108 Tasmanian Uplands Province	Widespread hillslope erosion in the west and south-west due to wildfire, and under intensive agriculture in the north	?			
201 Carpentaria Lowlands Province	Largely undeveloped, but hillslope and gully erosion could increase with land clearing	?			
202 Central Lowlands Province	In the Central West region of New South Wales, 25% of soil monitoring units report sheet erosion as an issue; 4% report gully erosion as a problem; 4% report wind erosion as a problem	—			
203 Murray Lowlands Province	Extensive wind erosion, but improving with increased surface cover	↗			

Assessment summary 6 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
301 North Australian Plateaus Province	Good, but vulnerable to severe erosion as a result of intensity of rainfall	Good, ?	◔	○	◒
302 Kimberley Province	Rates of sheet and gully erosion have slowed but remain unsustainable in areas with poor surface cover	Poor, ?	◔	○	◒
303 Carpentaria Fall Province	Erosion rates have slowed, particularly in the south-east of the province	Good, ?	◔	○	◒
304 Barkly–Tanami Plains Province	Good, but vulnerable to severe erosion as a result of intensity of rainfall	Good, ?	◔	○	◒
305 Central Australian Ranges Province	Subject to wind erosion, with gully and sheet erosion in areas grazed by stock and feral animals	Poor, ?	◔	○	◒
306 Sandland Province	Probable wind and waterborne erosion in areas subject to grazing by stock and feral animals	Good, ?	◔	○	◒
307 Pilbara Province	Vulnerable to severe wind and waterborne erosion due to cyclones, and grazing by stock and feral animals	Poor, ?	◔	○	◒
308 Western Coastlands Province	Vulnerable to moderate erosion due to weather activity, low groundcover and erodible soils	Good, —	◕	◕	◒
309 Yilgarn Plateau Province	Vulnerable to wind erosion due to low groundcover and erodible soils	Poor, —	◕	◕	◒

Assessment summary 6 (continued)

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good) — Confidence (In grade / In trend) — Comparability (To 2011 assessment)
310 Nullarbor Plain Province	Good groundcover reduces erosion hazard	
311, 312 Eyre Peninsula and Gulfs Ranges Provinces	Diverse land uses, with a history of unsustainable rates of wind and water erosion, but improving under sustainable land management practices such as no-till agriculture	

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very good:** Current management is adequate, and a low level of monitoring is required
- **Good:** Significant erosion at the time of clearing (>5 tonnes/hectare/year). Rates are 1–5 tonnes/hectare/year. Needs management and monitoring, or the system of land use will be threatened in the long term
- **Poor:** Majority of landscape has been eroded to the extent that plant growth has been affected and, in agricultural systems, yields and returns are compromised. Erosion rates are unsustainable (>5 tonnes/hectare/year)
- **Very poor:** Current rates of erosion are unsustainable; large areas will reach exhaustion within 50 years

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Vegetation

Forests and woodlands together represent about 16 per cent of the area of the Australian continent (124.7 million hectares); of this, 41 per cent is in Queensland, 18 per cent in New South Wales, 15 per cent in Western Australia and 12 per cent in the Northern Territory (ABARES 2014). The *National inventory report 2012* reported a net gain in forest cover in Australia between 2005 and 2012 of 1.6 million hectares (DoE 2014c). The continental extent of all forms of vegetation is summarised in Table LAN5 and mapped in Figure LAN26 (ABARES 2014).

Eucalyptus forests make up 74 per cent of Australia's national forest estate, *Acacia* forests 8 per cent, *Melaleuca* forests 5 per cent, and rainforest types just 3 per cent of the total (Figure LAN27). Industrial plantations of exotic species contribute 2 per cent of the total forest extent (ABARES 2014), but produced 82.7 per cent of the wood supplied by Australian forests in 2012–13.

Native vegetation

Numerous reports have analysed Australia's native vegetation condition and extent since 2011. The precise figures—for example, relating to clearing, conversion and regrowth—differ depending on the data and methodology used; however, the overarching picture remains consistent. Rates of clearing have generally decreased in Australia since a peak in 2006, and have stabilised in most states since 2011. However, in Queensland, clearing increased during the period 2011–14.

The rate of reclearing (i.e. clearing of forest cover that has regrown on previously cleared land) has also remained relatively stable since 2011 (DoE 2015).

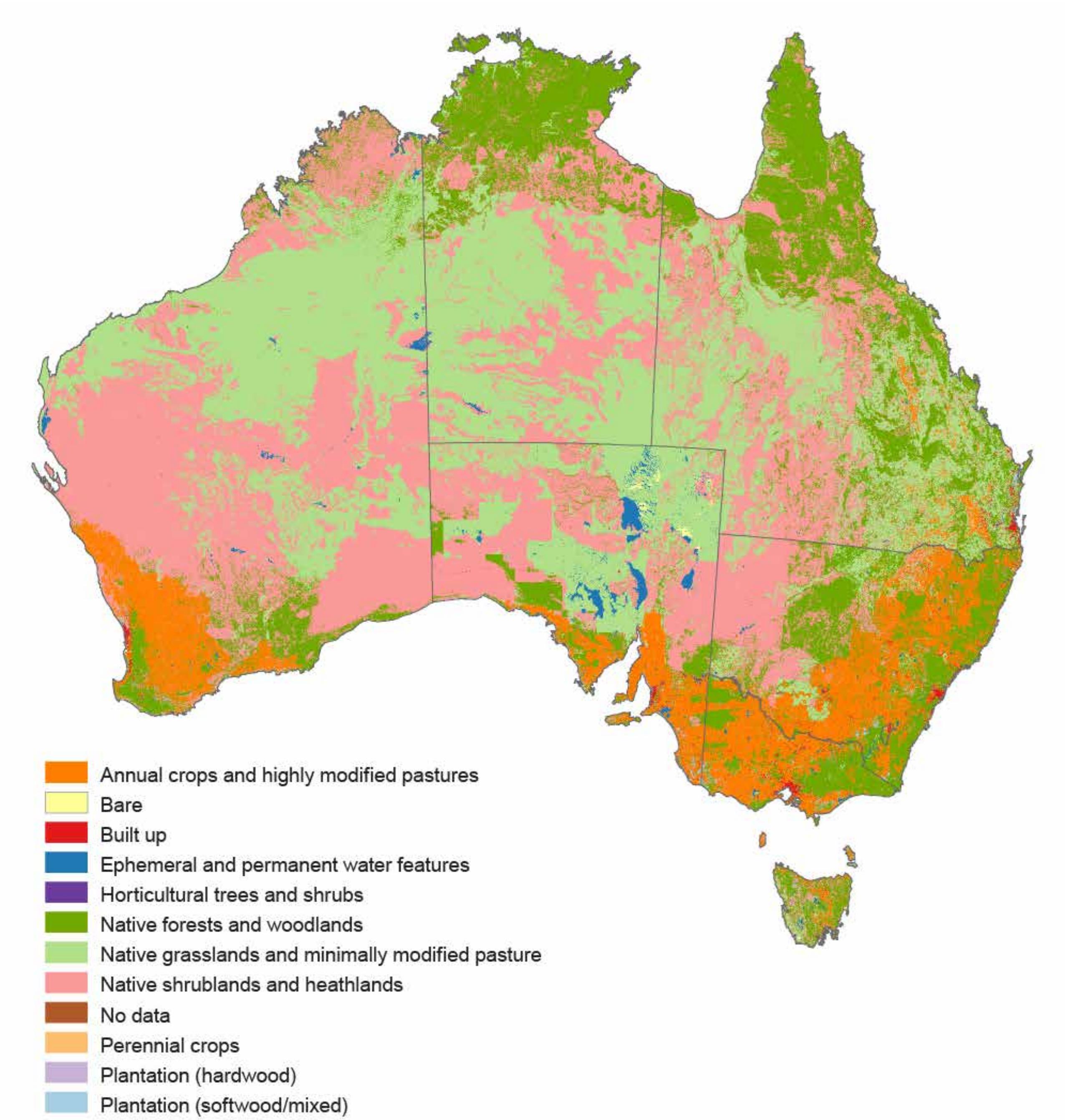
Extent

Many vegetation communities in Australia have been heavily cleared since European settlement. For example, approximately 30 per cent of Australia's land area was covered in forest before European colonisation; today, only about 16 per cent of the land area is forest (MPIG & NFISC 2013). Deforestation rates have decreased in each successive decade since the 1980s, and have also decreased as a proportion of the amount of primary (old-growth) native forest left (Evans 2016). However, about 1 million hectares of forested land were cleared in 2000–14, although much of this area was regrowth (Figure LAN5). For most years, the level of tree clearing in Queensland is greater than the combined total for all other states and territories. The main cause of clearing is for pasture (Figure LAN28a). About 75 per cent of clearing takes place on freehold land (Figure LAN28b), even though this only accounts for 31 per cent of the landscape (Evans 2016).

Table LAN5 Continental extent of Australian vegetation

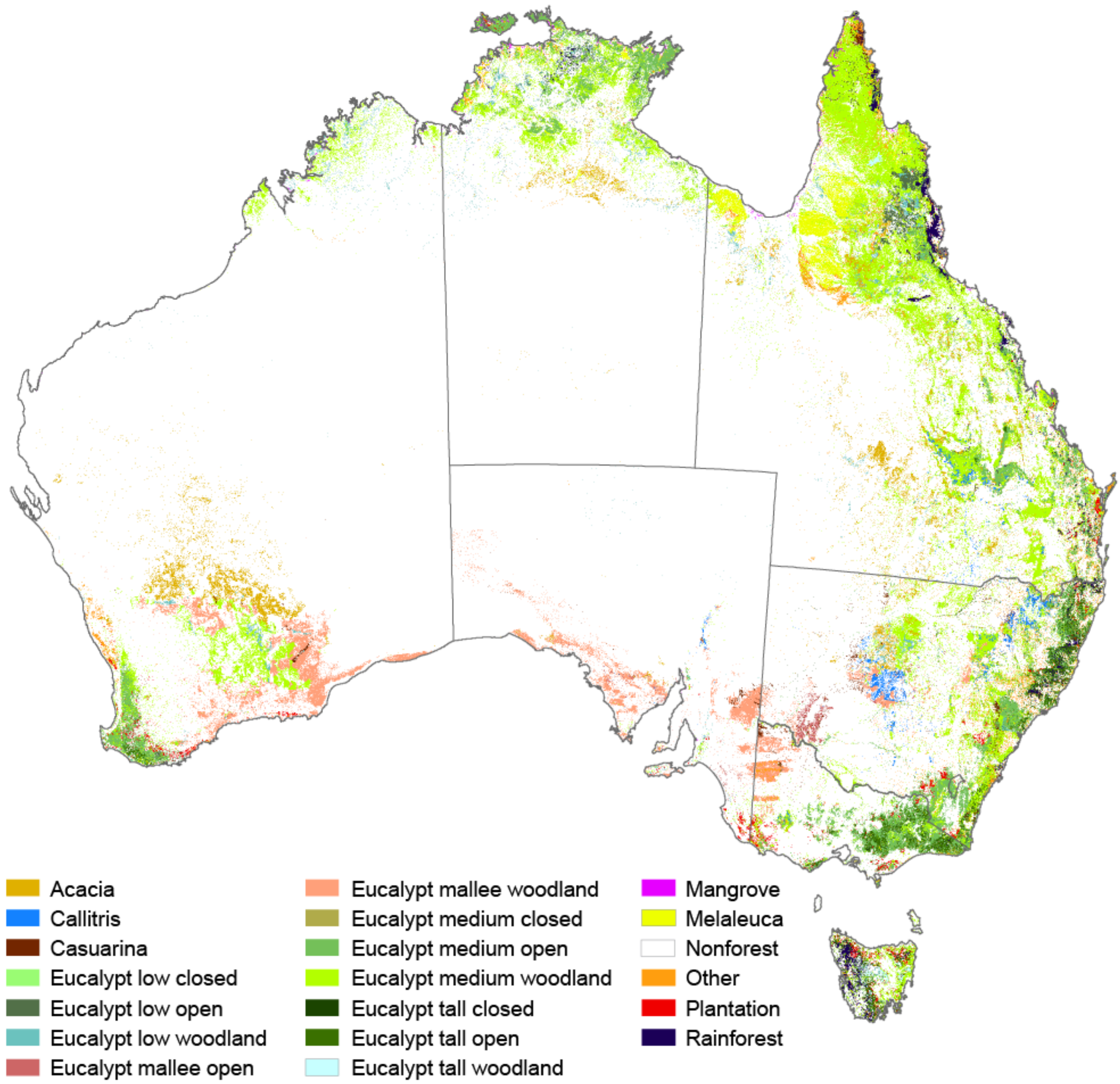
Vegetation category	Area (million hectares)	Area (%)
Native shrublands and heathlands	283	37
Native grassland and minimally modified pastures	257	33
Native forests and woodlands	148	19
Annual crops and highly modified pastures	66	9
Ephemeral and permanent water features	7	1
Intensive uses (including urban, peri-urban, mining)	3	0.4
Plantation forests	2	0.2
Perennial crops	1	0.1
Bare	1	0.1
Horticultural trees and shrubs	0.7	0.1
Total	**769**	**100**

Source: Australian Bureau of Agricultural and Resource Economics and Sciences, Integrated Vegetation Cover dataset 2009, used under CC BY 2.5



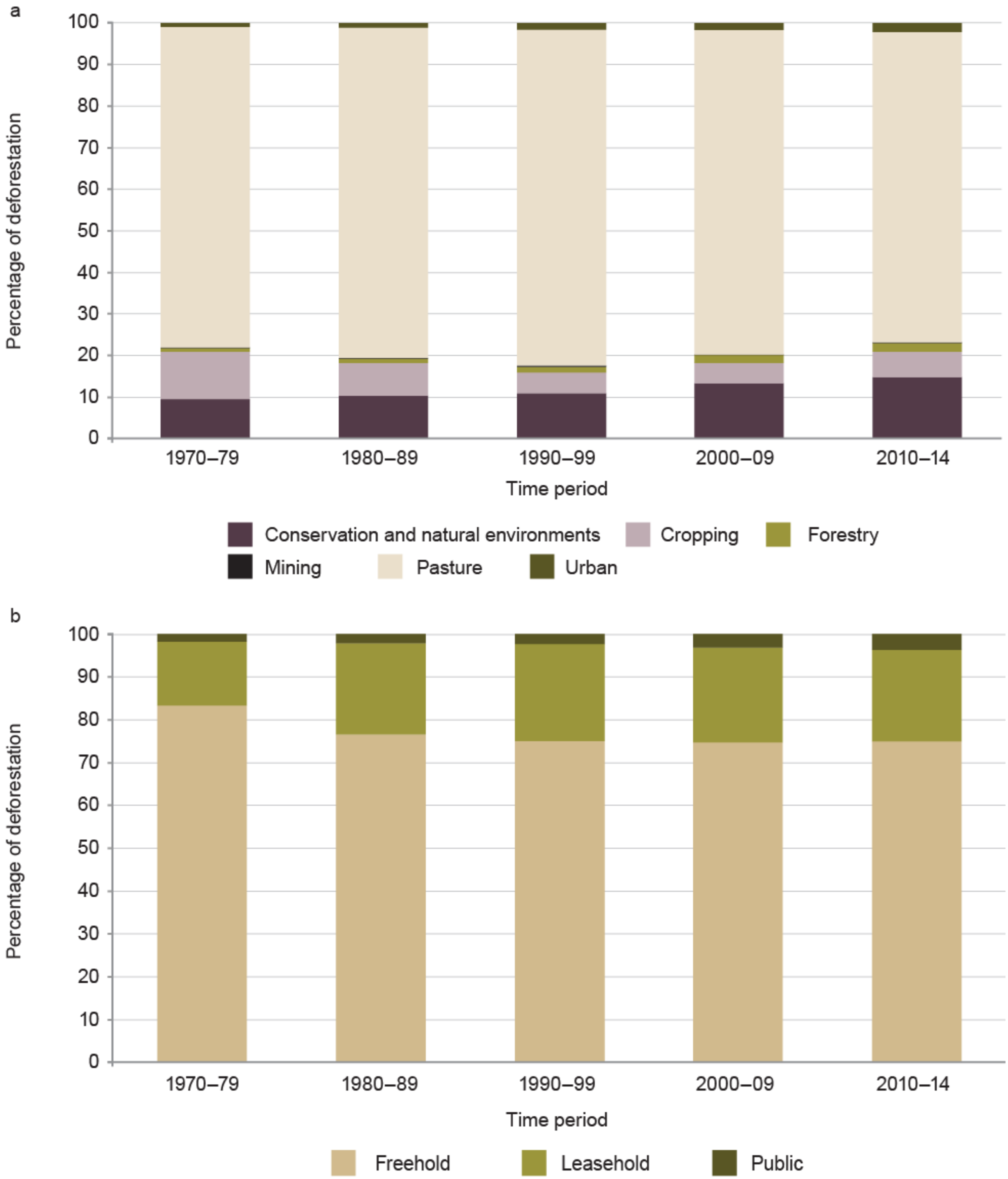
Source: Australian Bureau of Agricultural and Resource Economics and Sciences, Integrated Vegetation Cover dataset 2009, used under CC BY 2.5

Figure LAN26 Extent of all forms of vegetation across Australia



Source: Australian Bureau of Agricultural and Resource Economics and Sciences, Forests of Australia 2013, used under CC BY 3.0

Figure LAN27 Australia's forest extent by forest type



Source: Reproduced from Evans (2016), with permission from CSIRO Publishing

Figure LAN28 Percentage of total deforestation in each decade by (a) land use (as of 2005–06) and (b) land tenure (as of 1993)

The scale and rate of clearing vary among vegetation communities. A recent report by Tulloch et al. (2015) showed that, of 75 vegetation communities assessed (according to the Australian Government's National Vegetation Information System—NVIS 4.1, and excluding nonvegetation and cleared vegetation types), 32 per cent had lost at least 20 per cent of their original extent, and 7 communities had lost more than 40 per cent of their original extent. The 3 most heavily cleared communities (mallee with a tussock grass understorey, brigalow, and temperate tussock grasslands) together previously covered more than 170,000 square kilometres of Australia, and each has less than 20 per cent of its original extent remaining. In comparison, 19 vegetation communities have lost a very small proportion (less than 2 per cent) of their original extent.

Condition

Vegetation condition is effectively a subjective assessment of the health of an ecosystem, and so takes into account a suite of factors operating at different spatial and temporal scales. The most important factors are the extent of a community relative to its former extent, the extent of invasion by invasive species, and the degree of fragmentation within that remnant extent. Climatic impacts, such as the effects of drought, flood and wind storms, have been affecting vegetation for millennia, but these effects can be magnified if communities are limited in extent or highly fragmented. Much of Australia's remaining forest, shrubland, grassland and open woodland ecosystems are now degraded or fragmented (Tulloch et al. 2015, Evans 2016). A result of fragmentation is that smaller patches of habitat are now a common feature in many landscapes and represent an increasingly large component of remaining habitat for many ecosystems (Tulloch et al. 2015). Approximately 22 per cent of major vegetation communities in Australia have more than 50 per cent of their remaining extent in patches less than 1000 hectares. The contribution of patches less than 5000 hectares has increased in almost all areas of Australia, and significantly so along the east coast and in the south-west (Figure LAN6b). Other anthropogenic impacts, such as weeds, feral animal grazing and altered fire regimes, decrease vegetation condition.

Historically, vegetation condition has been assessed at a range of scales and using a variety of approaches. Progress has recently been made towards developing a nationally consistent approach to assessing vegetation condition; however, national-level results from this work are not yet available. In the interim, related parameters that provide insights into native vegetation condition at a continental scale are:

- the degree of fragmentation of native vegetation (Figure LAN6)
- annual and seasonal variation in green vegetation cover (mean annual greenness fraction—the fraction of land surface covered by photosynthesising green vegetation, which reflects variation in net primary productivity as a proxy for vegetation condition and indicates risk of erosion; see Figure LAN22)
- the degree of vegetation modification, as assessed under the 'vegetation assets, states and transitions' (VAST) framework developed by the Bureau of Rural Sciences.

The degree of modification of Australia's native vegetation across Australia's land area as assessed by VAST is illustrated in Figure LAN29. This classification is provided by continental-scale remotely sensed data, and is most useful for broad regional assessments rather than fine detail.

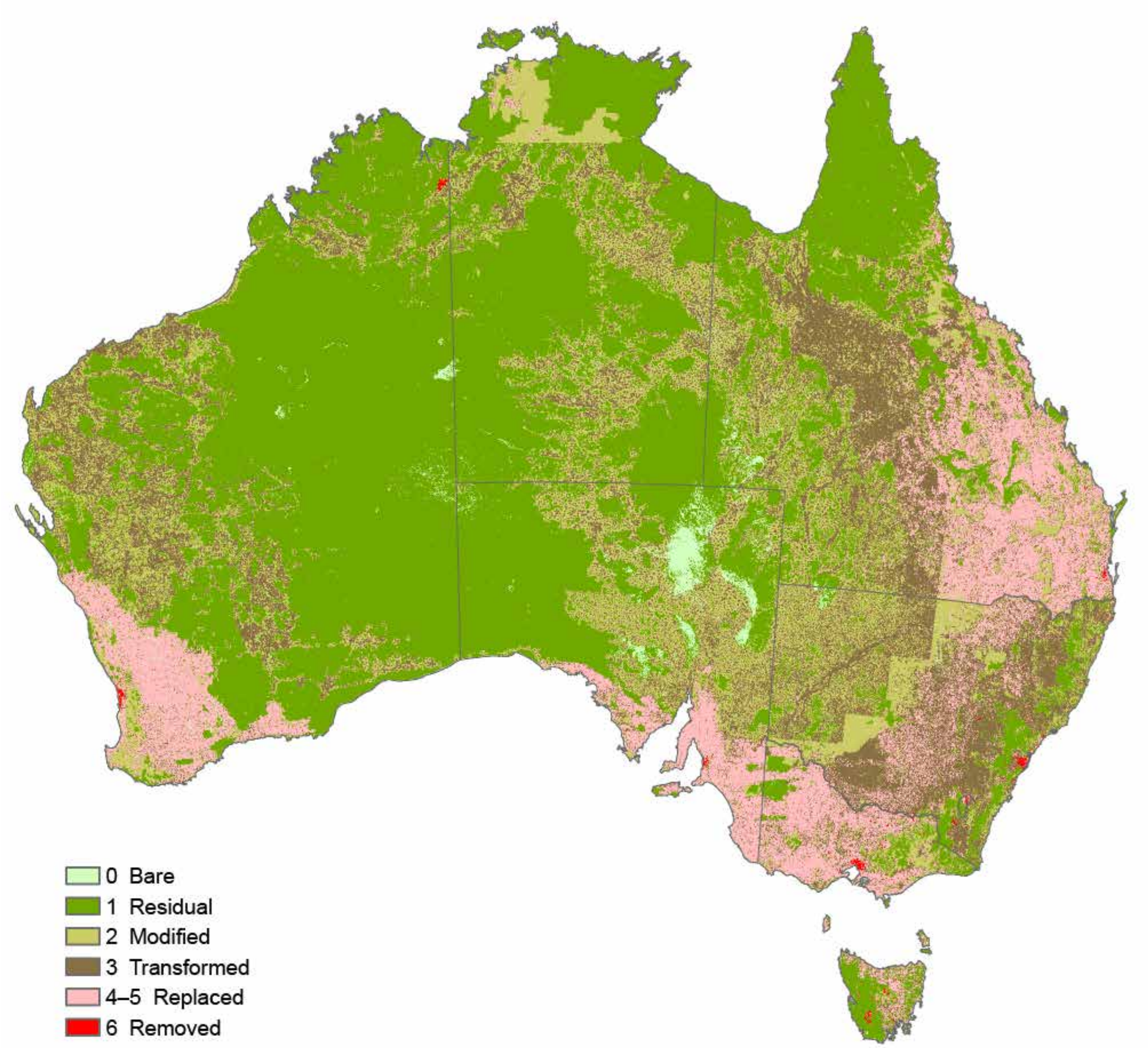
Again, the continental pattern of vegetation modification reflects Australia's history of European settlement, land clearing and agricultural land uses, and—perhaps less obviously—the legacy of 50,000 years of Indigenous land management practices. The greatest extent of least-modified vegetation is in the north and centre of the continent, along the eastern and south-western ranges of mainland Australia, and in the eastern ranges and south-west of Tasmania. In these zones, an average of 80 per cent (range 70–96 per cent) of vegetation is classified as VAST category I or II (residual or modified; for definitions, see Table LAN6). Conversely, the greatest extent of most-modified or replaced vegetation is in the intensive-use zones of the eastern and southern mainland, and in the midlands and north of Tasmania. In these zones, an average of only 40 per cent (range 15–69 per cent) of vegetation is classified as VAST category I or II.

Figure LAN30 illustrates the extent of modification of each of the major vegetation groups, as assessed by VAST.

Table LAN6 Vegetation assets, states and transitions (VAST) classification framework

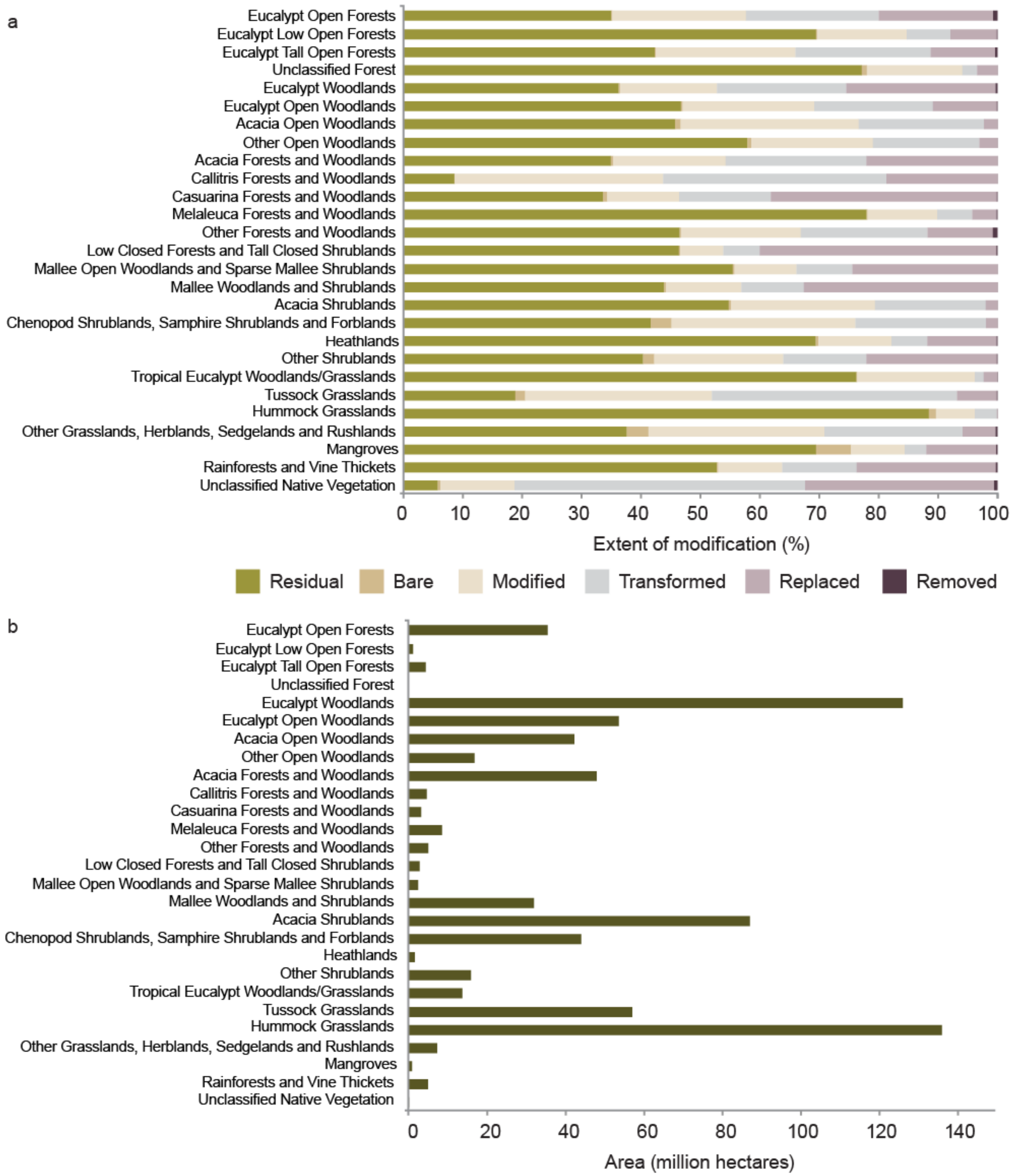
Increasing modification →							
	Native vegetation cover Dominant plant species indigenous to the locality and spontaneous in occurrence (i.e. a vegetation community described using definitive vegetation types relative to estimated pre-1750 types)				Non-native vegetation cover Dominant structuring plant species indigenous to the locality but cultivated, alien to the locality and cultivated, or alien to the locality and spontaneous		
Vegetation cover class	Class 0: residual bare	Class I: residual	Class II: modified	Class III: transformed	Class IV: replaced—adventive	Class V: replaced—managed	Class VI: removed
Criteria	Areas where native vegetation does not naturally persist	Native vegetation community structure, composition and regenerative capacity intact—no significant perturbation from land use or land management practice. Class I forms the benchmark for classes II to VI	Native vegetation community structure, composition and regenerative capacity intact—perturbed by land use or land management practice	Native vegetation community structure, composition and regenerative capacity significantly altered by land use or land management practice	Native vegetation replaced with species alien to the locality and spontaneous in occurrence	Native vegetation replaced with cultivated vegetation	Vegetation removed

Source: Thackway & Leslie (2008)



Source: Australian Bureau of Agricultural and Resource Economics and Sciences, National Scale Vegetation Assets, States and Transitions 2008, used under CC BY 3.0

Figure LAN29 Vegetation assets, states and transitions (VAST) classification of Australian vegetation



Source: Environmental Resources Information Network, Australian Government Department of the Environment and Energy

Figure LAN30 Extent of modification of major vegetation groups, as assessed by vegetation assets, states and transitions (VAST): (a) percentage of modification; (b) extent of major vegetation groups, pre-1750

Non-native vegetation

Non-native vegetation includes vegetation comprising solely exotic species, such as many annual and perennial crops, and native vegetation assemblages that have been significantly altered through management or invasion by exotic species. There is currently no generally agreed threshold for the level of alteration at which vegetation ceases to be classified as 'native', so there may be some imprecision in classification between, for example, VAST categories III and IV.

The dominant forms of non-native vegetation are annual crops and highly modified pastures, which together comprise around 9 per cent of Australia's land area (Table LAN2). All other forms of non-native vegetation each comprise less than 1 per cent of the continental land area: plantation forests comprise 0.26 per cent, perennial crops 0.14 per cent, and horticulture 0.08 per cent of our land area. Although there is currently interest in increasing the extent of irrigated agriculture, particularly across northern Australia, assessments of soil suitability and availability of predictable water supplies suggest that this is only likely to affect 1 per cent of the continental land area (Grice et al. 2013).

Irrigated corn crop with centre-pivot irrigator, Upper Herbert, northern Queensland
Photo by Dan Metcalfe, CSIRO

Assessment summary 7

State and trends of vegetation

Component	Summary	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Native vegetation extent outside intensive land-use zones	Declining clearance rates, but still significant impacts, particularly in Queensland	Good; Deteriorating	Adequate	Adequate	Comparable
Native vegetation extent within intensive land-use zones	Fragmentation means that smaller patches of native vegetation contribute a greater proportion of the remaining extent within intensive land-use zones	Poor; Deteriorating	Adequate	Adequate	Comparable
Native vegetation condition outside intensive land-use zones	Landscape-scale issues such as feral animals, altered fire regimes and invasive species are still threats. Resourcing to address particular issues is patchy and not undertaken in a holistic manner	Good; Deteriorating	Adequate	Adequate	Somewhat comparable
Native vegetation condition within intensive land-use zones	With most remnants small and isolated, condition deteriorates as exogenous influences play a greater role in reducing habitat quality	Poor; Deteriorating	Adequate	Adequate	Somewhat comparable

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- Improving
- Deteriorating
- Stable
- Unclear

Grades

- **Very good:** The environmental values of native vegetation are, or approximate, those that would be found in undisturbed vegetation; community structure, composition and regenerative capacity are intact
- **Good:** The environmental values of native vegetation are suboptimal, but community structure, composition and regenerative capacity remain largely intact
- **Poor:** The environmental values of native vegetation are significantly compromised and are unlikely to recover without intervention
- **Very poor:** The environmental values of native vegetation have largely been lost

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Effectiveness
of land management

At a glance

Institutional arrangements for the management of land have been relatively stable, although there has been considerable investment in reviewing existing strategies and developing new ones. Consolidation of much of the Australian Government's funding of the National Landcare Programme has streamlined some governance processes and coordinated investments, from the national to the local scale.

Investment in management of the land environment includes financial and in-kind commitments by all levels of government, private landowners and businesses, philanthropic and other nongovernment organisations, Indigenous Australians and communities. Government funding includes programs specifically directed towards land care, as well as programs that contribute to aspects of the land environment (e.g. the 20 Million Trees Programme) or to addressing the pressures on land (e.g. biosecurity programs).

Increased Indigenous ownership and management of land, particularly in remote areas, provide important ecological, social, political and economic outcomes from looking after Country. Less complex and more dynamic funding and governance arrangements would improve these opportunities.

Management context

Legislative arrangements for the management of public lands continue to be relatively stable, despite flux in the names, structures and specific responsibilities of the government departments and agencies that oversee management. Similarly, although private and Indigenous landowners may be subject to varying levels of regulation and constraint, the institutional arrangements under which they manage land are relatively stable.

The previous Australian Government's Caring for our Country program was implemented in 2008, partly as a response to criticisms from the Australian National Audit Office and others that it was difficult to assess the outcomes and impacts of natural resource management (NRM) investments. Caring for our Country recentralised decisions about NRM investment funding under 6 priority areas, and focused on measurable, short-term outputs. Caring for our Country, together with Landcare, were rebranded in 2013 as the National Landcare Programme.

The Australian Government is conducting a review of the National Landcare Programme to assess its effectiveness and achievements, and future options for NRM arrangements. This review will inform government decisions about the future of the program.

The 2015 *Agricultural competitiveness white paper* included a focus on 'strengthening our approach to drought and risk management', which made commitments to improving drought forecasting, and managing pest animals and weeds in drought-affected areas. It also supported 'farming smarter', including through funding of $50 million to boost Australia's emergency pest and disease eradication capability. The National Landcare Programme's Sustainable Agriculture Small Grants scheme, worth $2.2 million in 2015–16, complements the delivery of the *Agricultural competitiveness white paper* by facilitating the adoption of management practices that maintain or enhance the natural resource base.

Another area in which significant changes have taken place with overarching consequences for land management is biosecurity. The National Environmental Biosecurity Response Agreement (NEBRA) was signed by the Australian Government, and all state and territory governments in January 2012. NEBRA operates in tandem with the Emergency Animal Disease Response Agreement and the Emergency Plant Pest Response Deed in providing national arrangements for eradication responses to pest or disease incursions (see Diseases, pests and weeds). In addition to these arrangements, private landholders are most likely (and, in some cases, required) to manage pests, diseases and feral animals that affect agricultural production.

In August 2014, the Australian Weeds Committee and the Vertebrate Pests Committee merged to form the Invasive Plants and Animals Committee (IPAC). IPAC provides an intergovernmental mechanism for identifying and resolving weed and vertebrate pest issues at a national level. It is a cross-jurisdictional committee with members from the Australian Government, and all state and territory governments. Priorities for IPAC have included reviewing and updating the Australian Pest Animal Strategy and the Australian Weeds Strategy.

The area with perhaps the greatest uncertainty is the ability of legislative and management arrangements to respond to future challenges posed by significant issues such as population growth and the impacts of climate change. A National Climate Resilience and Adaptation Strategy (Australian Government 2015a) was released in 2015 to affirm a set of principles to guide effective adaptation practice, and identify areas for future review and action.

Institutional arrangements

In 2012, the Australian Government, in collaboration with state and territory governments, released Australia's Native Vegetation Framework (COAG Standing Council on Environment and Water 2012), which aimed to maintain or build more connected native vegetation. This was produced partly as a response to SoE 2011. It sets targets to help ensure that the ecological, economic, social and cultural value of native vegetation is realised and its resilience is increased.

The management of Australia's forests is guided by the National Forest Policy Statement (Australian Government 1995), which was signed by the Australian Government and all mainland state and territory governments in December 1992, and by the Tasmanian Government in April 1995. This statement laid the foundations for the regional forest agreements, which are 20-year bilateral agreements between the Australian and state and territory governments. The agreements identify areas required for establishing a comprehensive, adequate and representative forest reserve system. They aim to achieve a balance between conservation, ecologically sustainable management of Australia's native forests, and the long-term stability of forest industries.

Under the requirements of the *Water Act 2007* (Cwlth), a Basin Plan for the Murray–Darling Basin was developed to help achieve a balance between extracting water for human use and retaining water for the environment. The Basin Plan came into effect in November 2012 with a 7-year implementation phase. The Basin Plan is built on extensive social and economic data, in addition to data on environmental and industrial uses of water. It marks a significant step in cross-jurisdictional development of a framework for NRM in a highly complex and politicised context.

In January 2012, an Intergovernmental Agreement on Biosecurity came into effect between the Australian Government and all state and territory governments, with the exception of Tasmania, and is now being independently reviewed. The stated aims of the agreement are to strengthen the working partnership between governments, and to improve the national biosecurity system to minimise the impact of pests and disease on Australia's economy, environment and community. Progress has been made against several priority areas since the agreement came into effect, including a national framework to provide integrated and collaborative approaches to biosecurity surveillance; communication and engagement; research, development and extension for both plant and animal biosecurity; and management of established pests and diseases of national significance. A National Biosecurity Research and Development Capability Audit has also been completed (IGAB RDEWG 2012). Issues identified by the audit included maturation of the workforce and a lack of succession planning, and a reliance on short-term, unstable external funding that does not support capability development and clarity in career pathways.

The current environmental offsets policy under the EPBC Act aims to compensate for significant impacts on matters of national environmental significance relative to a 'business-as-usual' baseline (DSEWPaC 2012, Maron et al. 2013), which, as described by Maron et al. (2015), is one of ongoing biodiversity decline. Although not directly related to native vegetation policy and management by the states and territories, the declining baseline assumed by the national environmental offsets policy suggests that the national target of a net increase in native vegetation is not expected to be met (Evans 2016). Any future discussion about offsets under the EPBC Act should also consider whether an evaluation is needed of success in obtaining 'permanently' protected offsets, and assessing their ongoing health and management.

Resources and capacity for management

Investment in management of the land environment includes financial and in-kind commitments by all levels of government, private landowners and businesses, philanthropic and other nongovernment organisations, Indigenous Australians and communities. Each of these is considerable, but most—particularly the commitment of time by individuals, groups and communities—are difficult to quantify. Indigenous land and sea management activity can also be difficult to scope in economic terms, because much of it is ceremonially driven and thus private.

Natural resource management funding

Australian governments' NRM expenditure includes expenditure on public lands, such as national parks, state forests and lands under local government control. The previous Australian Government's flagship environment program, Caring for our Country, concluded in 2013, following an investment of $2.15 billion during the 5-year period from 2008. Another $316.7 million was paid in 2013–14 as part of the first year of Phase 2 of Caring for our Country. Since the mid-1990s, the Australian Government has contributed to the National Reserve System by investing $200 million in partnering with on-ground managers to purchase 370 properties for inclusion in the National Reserve System.

In 2014, the incoming Australian Government announced the establishment of the new National Landcare Programme, merging the previous Caring for our Country and Landcare programs, with a budget of $1 billion over 4 years from 2014–15.

The National Landcare Programme is based on the principles of 'simple, local and long term'. It supports communities to take practical action to protect and manage Australia's important environmental assets and production landscapes. The program comprises a regional stream and a national stream. Under the regional stream, funding is provided to Australia's 56 regional NRM organisations, which, in turn, have committed at least 20 per cent of their National Landcare Programme funding to help support local organisations. The national stream supports important initiatives such as the 20 Million Trees Programme, and continuing commitments such as World Heritage Areas and Indigenous Protected Areas.

The majority of investment through the National Landcare Programme is committed until 2017–18; funding and the approach beyond that time have not yet been determined. Development of a considered approach to NRM investment beyond 2017–18 would lay the foundation for long-term funding by the Australian Government. It would assist the Australian Government to make an informed, evidence-based decision about effective and efficient means of delivering on its priorities and international obligations. This would improve the Australian Government's ability to report on outcomes and prioritise future investment.

Investment in the Landcare Programme has been supplemented by other Australian Government programs. Significant investment was directed through the Biodiversity Fund between 2011–12 and 2017–18, providing approximately $350 million to increase the condition, extent and connectivity of native vegetation in project areas. The Green Army, which launched in 2014, is a hands-on, practical environmental action program that supports local environment and heritage conservation projects across Australia. The program delivers environmental outcomes by working with communities and building partnerships at the local and regional levels. The Australian Government has provided more than $410 million for the program for the 5 years from 1 July 2014 to support a total of 1250 projects. Other sources of funding that contributed to the Australian Government's investment in NRM from 2014–15 include the Working on Country Indigenous Rangers ($238 million over 4 years from 2014–15) and the Reef Trust (currently $180 million over 6 years from 2014–15).

Biosecurity is supported through initiatives such as funding of the National Wild Dog Action Plan, and resources to support national emergency responses to newly identified incursions of pests and diseases.

The Emissions Reduction Fund provides an additional source of Australian Government investment in land. The fund provides incentives for greenhouse gas emissions reduction activities across the Australian economy, including both carbon sequestration and emissions avoidance activities. Sequestration opportunities for the land sector include management of grazing land to increase soil carbon, expanding opportunities for tree planting, and farm forestry. Emissions reduction opportunities include adopting fire regimes that reduce fire extent and intensity (see Box LAN8), and managing cattle to improve growth rates and reduce lifetime methane production.

Investment in Indigenous land and sea management

Indigenous lands include some of the most biodiverse lands in Australia, which also contain species of national significance that are at risk (Altman et al. 2007, Altman & Jackson 2008). Indigenous land interests contain large areas that are of high conservation value—that is, significant portions of the Indigenous estate remain relatively ecologically intact and have not been subjected to the intense level of development pressure experienced in many other areas, particularly in southern Australia. Finally, much of the Indigenous estate (particularly in northern and central Australia) features vast areas of relatively undisturbed, connected, ecologically healthy, functioning environments and waterways that provide a variety of habitats and ecosystem services. However, to date, no national study or reviews have been undertaken that provide a specific measure of the conservation value or biodiversity status of Indigenous land interests. Altman et al. (2007) provide a broad overview of some of the key conservation values of the Indigenous estate using existing studies, analyses and planning frameworks, by examining the relationship between the Indigenous estate and conservation values. A series of maps (Altman et al. 2007) visually represent the relationship between the Indigenous estate and conservation values, and have contributed to a much more informed debate regarding the role of Indigenous Australians in land management.

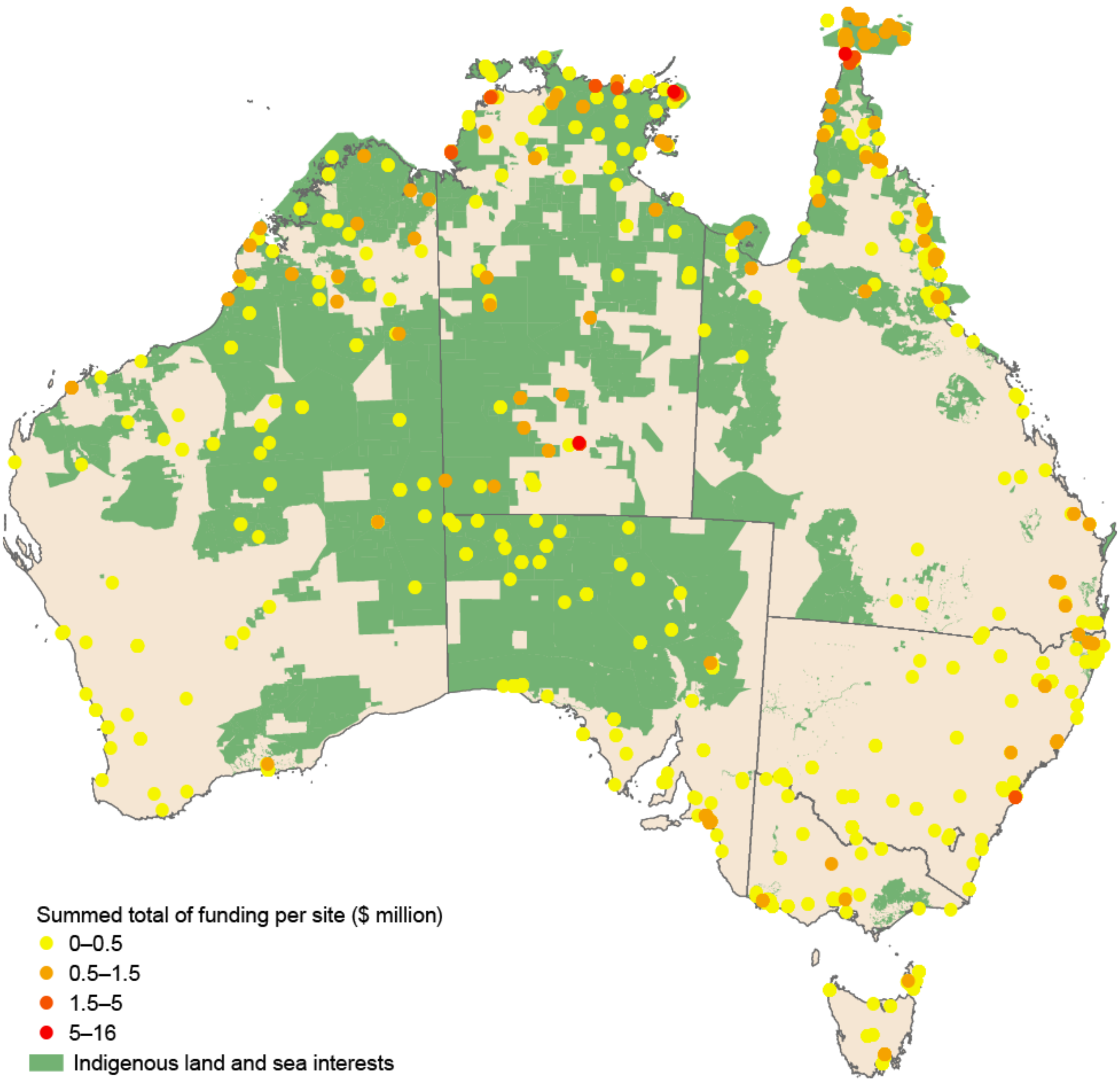
The role of Indigenous Australians in land management is formally recognised by Australia's key piece of environmental legislation, the EPBC Act, in terms of 'a partnership approach to environmental protection and biodiversity conservation' that recognises and promotes 'Indigenous peoples' role in, and knowledge of, the conservation and ecologically sustainable use of biodiversity' (s. 3[2][g][iii]).

Indigenous land management is supported by a range of programs that provide an important source of employment, primarily for rangers, and resources for many groups in remote and very remote parts of Australia to look after Country (see Boxes LAN11 and LAN12). These programs must prioritise limited resources, and negotiate differences in values and perceptions for NRM (Weston et al. 2012, Muller 2014). Planning programs that enable Indigenous groups to manage multifunctional landscapes for biodiversity, culture and income generation can provide greater certainty for ecological, social, political and economic outcomes from looking after Country (see Ens et al. 2015). For example, ecosystem service payments have been made available for northern Aboriginal communities to manage feral buffalo (*Bubalus bubalis*)—one of the many pest plant and animal species. Zander and Garnett (2011) have recently estimated that Australians could be willing to pay $878 million to $2 billion per year for Indigenous people to provide environmental services, including feral animal control, coastal surveillance, weed control and fire management.

The Australian Government established the Working on Country program in recognition that protecting and conserving the environment is a shared responsibility, and provides sustainable employment for Indigenous people. Working on Country builds on Indigenous traditional knowledge to protect and manage land and sea Country. Almost 700 Indigenous rangers across 108 ranger teams are employed across Australia to deliver environmental outcomes. Australian Government funding for the program was more than $192 million from July 2013 to June 2016. At least $475 million of investment in Indigenous land and sea management projects has occurred during 2011–16 at 543 sites throughout Australia, predominantly funded by the Working on Country initiative, but also through a range of other programs such as the Biodiversity Fund, Caring for our Country, Community Action Grants, the National Landcare Programme, Clean Energy Future, the Indigenous Carbon Farming Fund, Indigenous Protected Area management and business plans, and Wild River Rangers. Investment in Indigenous land

and sea management has decreased from $106 million in 2011–12 to $81 million in 2015–16. Indigenous land and sea management projects supported through the Indigenous Advancement Strategy are funded through to 2018.

Figure LAN31 shows that investment in Indigenous land and sea management is primarily in the Northern Territory and other parts of northern Australia, and on Indigenous land and sea interests across Australia. However, there are noticeable gaps in South Australia and inland Queensland.

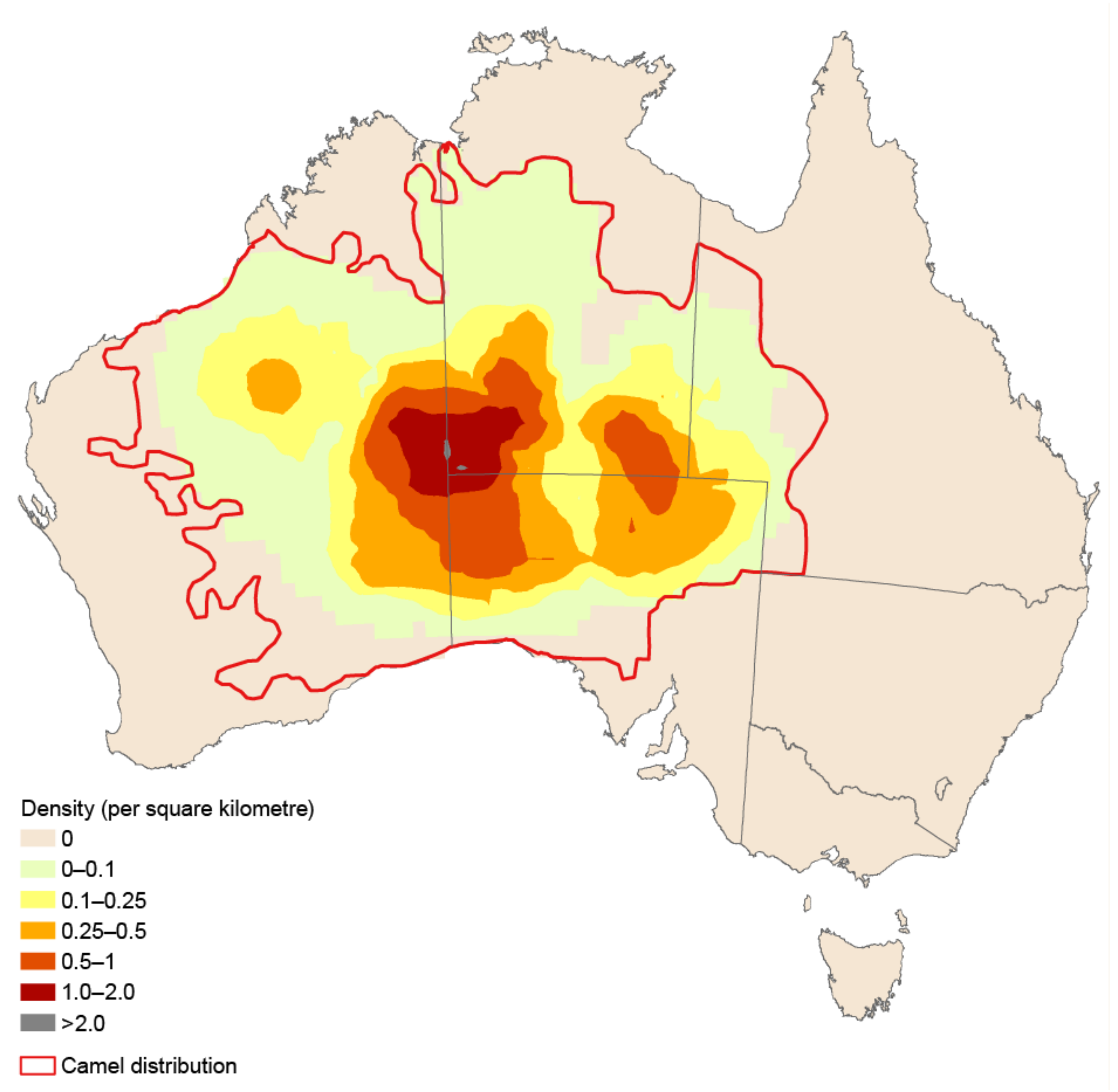


Source: Petina Pert (CSIRO), using data obtained from the Indigenous Land Corporation; and various online sources, including Australian Government websites and philanthropic organisations such as Myer, The Christensen Fund, Australian Environmental Grantmakers Network, Lottery West, Pew Environment Group and The Nature Conservancy, used under CC BY 3.0

Figure LAN31 Investment in Indigenous land and sea management, 2011–16

Box LAN11 Australian Feral Camel Management Project

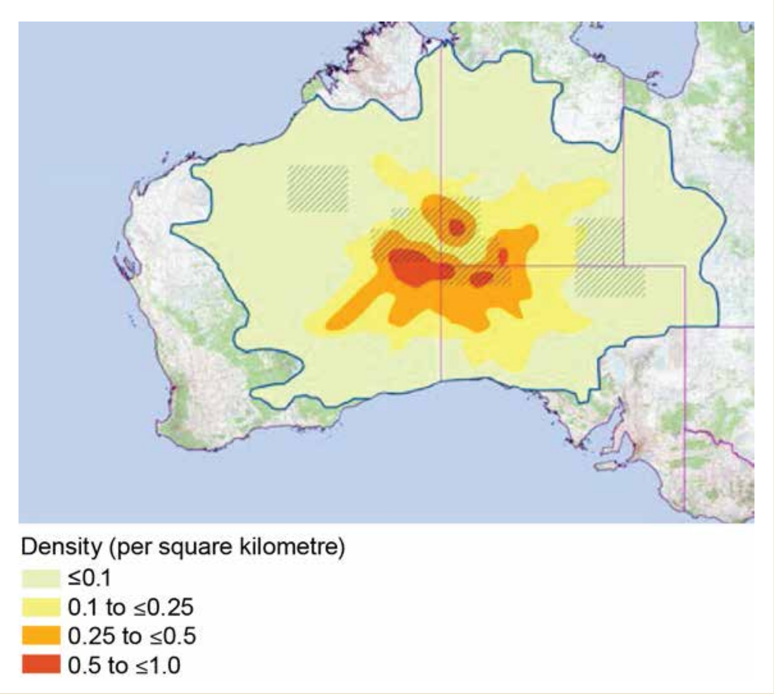
Camels (*Camelus dromedarius*) were introduced to Australia from 1840, and, by 2008, an estimated 1 million camels were roaming the central arid lands of Western Australia, the Northern Territory, South Australia and Queensland. Major impacts are damage to native vegetation and wetlands; competition with native animals for food, shelter and water resources; damage to infrastructure; and road hazards. The Australian Feral Camel Management Project removed more than 160,000 camels, supported the development of a commercial feral camel industry and contributed to a reduction of the feral camel population to around 300,000 by 2013 (Figures LAN32 and LAN33).



Source: Data supplied by the Department of the Environment and Natural Resources, © Northern Territory of Australia, used under CC BY NC-SA 4.0

Figure LAN32 Density distribution of feral camels across their range in Australia, 2008

Box LAN11 (continued)



Source: © Northern Territory Department of the Environment and Natural Resources, all rights reserved, as published in McGregor et al. (2013)

Figure LAN33 Density distribution of feral camels across their range in Australia, with aerial survey areas marked by hatching, 2013

Box LAN12 Feral camels on Oak Valley students' hit list

As most people living in the far west of South Australia are well aware, feral camels are highly destructive and, in large numbers, present a serious threat to the fragile local environment. The students from Oak Valley School, whose community is located on the southern fringe of the Great Victoria Desert, see first-hand the devastating effects that camels have on their environment, including on native plant and animal species, water supplies and sacred sites.

Motivated to share their story, the students wrote and illustrated their own book so that others could understand the problems that feral camels cause in and around the Oak Valley community.

The illustrated book describes how camels drink very large quantities of water, leaving empty rockholes behind with no water to sustain native populations. It talks about the way camels snap branches off overhanging trees and destroy scarce plants that grow under shaded areas, potentially wiping out local vegetation species such as quandong (*Santalum acuminatum*) and sandalwood (*Santalum spicatum*).

Oak Valley School worked with local community members and Natural Resources Alinytjara Wilur̲ara to develop the content for the book. Publishing was supported through the Feral Animals Enviro-Stories Program of the Invasive Animals Cooperative Research Centre (CRC).

'Seeing *Carl the pesky camel* published is amazing. It is a great credit to the kids and the Oak Valley community. The students' captivating illustrations give a unique insight into the significant damage that feral camels cause from the perspective of the people who experience it first-hand in their community', said Jessica Marsh from the Invasive Animals CRC.

'The kids loved finding the pictures that they had drawn and were thrilled to see a picture of themselves on the back cover; it's really proven to be a great tool for learning about pest animals and for telling others about our community', said the school principal, Ineke Gilbert.

Effective and humane removal of 'pesky' feral camels in this vast and remote region can only be from the air. In response to traditional owners' requests to manage the herd numbers, Natural Resources Alinytjara Wilur̲ara employed a highly skilled, appropriately certified marksperson to undertake aerial culling. As well as being able to cover and search large distances quickly, using a helicopter allows the marksperson to get close enough to the camels to deliver instantaneous fatal shots.

These operations are supported by locals, who are engaged to offer advice and direction to the team, and to assist with logistical considerations such as fuel dump locations and camp support. Traditional owners also fly over the region, and identify sacred areas and no-fly zones. These are mapped and used by the aerial team during culling activities.

'Sorry Carl, but being pesky does not bode well for you.'

Source: Alinytjara Wilur̲ara, Oak Valley community, South Australia

Knowledge

National SoE reporting began in 1996. In 2011, the fourth national SoE report concluded that, although a clear national picture of the state of Australia's environment was still incomplete, the situation had improved. Investments through programs such as the National Collaborative Research Infrastructure Strategy (NCRIS) have sought to pull together national baselines on, for example, the distribution of biodiversity (Atlas of Living Australia), vegetation cover (OzCover), and the Soil and Landscape Grid of Australia (see Box LAN9). All of these examples rely on multi-institutional collaborations involving collation and sharing of data, analytical platforms and modelling capacity. The future of NCRIS-like investment is being considered in the 2016 National Research Infrastructure Roadmap, which will report in 2017 on how best to support future investment decisions in research infrastructure.

In Australia, most environmental information relating to the land continues to be collected by public agencies through short-term projects. Loss of capacity as relevant Australian Government initiatives came to an end was identified as a management issue in SoE 2011. In 2016, we have found that, although there are still gaps, technological developments in remote sensing and cross-institutional collaborations are helping to plug them (see The changing nature of mapping, monitoring and forecasting). Significant quantities of environmental data are collected by individual land managers, community groups and private companies (e.g. to support environmental impact statements). Although the data are still rarely made available in information systems for others to use, there have been significant investments in building the infrastructure and capacity to facilitate sharing of data. Several of these are discussed below.

The changing nature of mapping, monitoring and forecasting

Lack of information affects our ability to assess the condition and trend of our environment, and limits management effectiveness by restricting accurate planning and monitoring of management strategies. For example, the Australian Business Roundtable for Disaster Resilience and Safer Communities commissioned a report, *Building an open platform for natural disaster resilience decisions* (Deloitte 2014), to help understand research and available data relevant to managing extreme events and natural disasters, in response to a series of floods, storms and bushfires that have devastated life and property across Australia. In addition to collaboration and data sharing, technological advances in capture, collation and analysis of environmental information are revolutionising the way in which land managers, agency staff and policy-makers can access and use information to support evidence-based decision-making.

For example, more than $50 million has been invested by the Australian Government in the Terrestrial Ecosystem Research Network (TERN) through NCRIS to enable ecosystem scientists to collect, contribute, store, share and integrate data across disciplines. TERN encourages collaboration and nationally consistent data, building digital infrastructure to store and publish this information in forms that can be searched and accessed freely.

Another NCRIS investment has been into the Atlas of Living Australia, a national database that enables researchers and other users to find, access, combine and visualise data on Australian plants and animals. The Atlas of Living Australia has been collaborating with the Australian Government to develop a new Monitoring, Evaluation, Reporting and Improvement Tool (MERIT) to support project and program requirements of Australian Government NRM initiatives. Launched in 2013, MERIT will improve program transparency, increase efficiency and allow project data to be used directly to report on biodiversity conservation work—including in future SoE reports.

Other initiatives include the streamflow forecasts published by the Bureau of Meteorology. Flow in Australian rivers and streams is hugely variable, yet is relied on by irrigators, urban and rural water supply authorities, environmental managers, hydroelectricity generators and others. Seven-day and 3-month streamflow forecasts are released regularly, drawing on data supplied by the states and territories, and using modelling approaches developed in partnership by the Bureau of Meteorology and CSIRO.

Despite these investments to improve mapping, monitoring and forecasting, the effectiveness of management actions to improve the state of the environment is not well understood. However, the Australian Government is investing in systems that will better synthesise current knowledge, and identify gaps where monitoring and research efforts could best be targeted. For example, the Knowledge Bank of Management Effectiveness project run by CSIRO is currently systematically searching for, and collating, published studies on management effectiveness. The resulting 'systematic map' will provide clarity about the relative confidence we have in the effectiveness of a broad range of environmental management actions. Where sufficient studies with enough data are available, the Knowledge Bank will also provide the foundation for rigorous analyses across studies to explore exactly how effective actions are in which circumstances.

Difficulties still exist in collating disparate datasets and information because of differences in timing, scale and management, but ongoing investment and collaboration are helping to overcome these hurdles—for example, using remotely sensed data to monitor habitat condition (see Box LAN13). A framework for coordinated national wind erosion monitoring, the DustWatch Product Integration Plan, has been outlined (Leys et al. 2013). Other significant developments in collating, managing and making available national data include the Australian Geoscience Data Cube, CSIRO's Data Access Portal and the Australian Soil Resource Information System. At the state and territory level, approaches such as the Queensland Globe provide public access to maps, imagery and spatial data inside the Google Earth application.

Box LAN13 HCAS—a new way to assess continuous variation in the condition of natural habitats for terrestrial biodiversity across whole regions using remote sensing data

In a recent article in *Methods in Ecology and Evolution* by Harwood et al. (2016), CSIRO reports on a novel approach to the difficulty in obtaining consistent and repeatable measurement of habitat condition for biodiversity across large areas, using remote sensing with limited field observations. The method requires 3 essential inputs: remotely sensed data, abiotic environmental data and condition reference sites. It aims to improve our capacity to identify natural and non-natural influences on habitat condition, identify priority areas for management interventions, and undertake national environmental reporting.

Habitat condition relates to the capacity of an area to provide the habitat structures and functions necessary for the persistence of plant and animal species that would be expected to occur at that location if it were still in a natural state.

Remote sensing can describe what a site looks like and how it behaves (using timeseries), but is unable to distinguish anthropogenic disturbances from natural ecosystem dynamics. The problem is compounded by the existence of multiple natural states in any given environment over time, and spatial variation in the composition and structure of vegetation as a function of variation in the abiotic environment.

The new approach addresses this challenge by comparing the remote-sensing signature of a reference site of known natural condition with the signature of a test site, both being equivalent in their abiotic environments (i.e. climate, soils, landscape). The difference in the remote-sensing signatures of the 2 sites provides an indication of the test site's departure from reference condition.

Building on this proof of concept, the Australian Government Department of the Environment and Energy, and CSIRO are developing the first operational application of a Habitat Condition Assessment System (HCAS) for Australia. New environmental informatics technologies arising from existing and emergent remote-sensing data cubes, data from the Atlas of Living Australia and the Terrestrial Ecosystem Research Network, and the National Computational Infrastructure will be critical to implementing HCAS at ever-finer resolutions. Output datasets will initially be delivered as 0.01 degree grids (representing around 1 kilometre), with potential to move to a finer resolution in the future (i.e. 9 seconds—around 250 metre grids). The project also aims to develop methods to routinely deliver HCAS products into the public domain.

Source: Kristen Williams, CSIRO

Human capital

Although positive developments in resourcing, evidence-based policy-making and management effectiveness are evident, ongoing improvements depend heavily on the quality and overall capacity of the human resources, networks and infrastructure involved in land planning and management. This aspect is being increasingly recognised as strategically important for the future, especially with consideration of the 'human dimensions' of land management. This includes the need for a better understanding of the motivations of, and barriers to, land managers and others to support and undertake improved land management practices.

Australia is highly urbanised: more than two-thirds of Australians live in capital cities, and there is an ongoing trend for people to move from regional areas into cities (ABS 2012a). Consequently, many Australians now have minimal direct contact with people in rural and remote regions. This affects both the awareness and the sophistication of public discourse on land-related issues (e.g. management of feral animals such as horses, risks and benefits of genetically modified organisms, management of fire in naturally flammable vegetation types).

The trend for people, particularly young people, to move from regional and rural to urban areas is reflected in the demographics of Australia's farmers: between 1981 and 2011, the proportion of farmers aged 55 years and over increased from 26 per cent to 47 per cent, while the proportion of farmers aged less than 35 years fell from 28 per cent to 13 per cent (ABS 2012b). However, since SoE 2011, the numbers of students taking higher degrees in agricultural sciences has increased, albeit from a very low point, stimulated by a growing interest in food and where it comes from, and food security (Parkinson 2016).

Social, economic and environmental benefits of Indigenous land and sea management

Investments in Indigenous land and sea management in the past 5 years have benefited Indigenous and non-Indigenous communities (Ryan et al. 2012, DSEWPaC 2013, SVA Consulting 2014, PM&C 2015, van Bueren et al. 2015). Reported benefits include:

- economic and market benefits, such as
  - increased employment and employability (Allen Consulting Group 2011, Ryan et al. 2012, Australian Government 2015b)
  - payment for ecosystem services, including lowered emissions in the carbon market (Green & Minchin 2012)
  - commercial bushfood and wildlife harvesting (Fordham et al. 2010)
- cultural benefits, such as
  - support for intergenerational knowledge transmission that reinforces culture (Sithole et al. 2007, DSEWPaC 2013; see Box LAN14)
  - greater recognition of women's roles in land and water management (Ryan et al. 2012)
- socio-political benefits, such as
  - strengthened ownership of land management programs and capacity for governance over land for which Indigenous people have exclusive or shared responsibility (van Bueren et al. 2015)
  - improved relationships between Indigenous people and agencies supporting Indigenous land management on Country (SVA Consulting 2014)
- health and wellbeing benefits, such as
  - reduced health risks and improved wellbeing from maintaining and connecting with Country, culture and community (Burgess et al. 2009, Thompson 2009)
  - local ownership of programs that have been developed by and with traditional owners, and a strengthened sense of identity (SVA Consulting 2014)
- environmental benefits, such as
  - activities in biosecurity surveillance, feral animal control, wildfire abatement, biodiversity conservation and protection of important water bodies (Barber & Jackson 2011, Weston et al. 2012, van Bueren et al. 2015, Australian Government 2016, Robinson et al. 2016a)
  - planning for Country and reassertion of ownership and management of Country (May 2010).

Despite these significant contributions to Indigenous and non-Indigenous society, the future of Indigenous Protected Areas and the Working on Country program remains uncertain beyond 2018.

Effect of severe tropical cyclone *Yasi* on a banana crop, Liverpool Creek, near Tully, Queensland

Photo by Dan Metcalfe, CSIRO

Box LAN14 Weeds, feral animals, fire and research at Wattleridge and Tarriwa Kurrukun Indigenous Protected Areas, New South Wales

The Banbai Aboriginal nation owns and manages 2 Indigenous Protected Areas (IPAs) in northern New South Wales. Wattleridge was the first IPA declared in the state, in 2001, and covers 648 hectares of native bushland. Tarriwa Kurrukun (which means 'strong one') covers 930 hectares of wetlands and stringybark forest. Both IPAs have a high diversity of plant and animal species, including threatened species, and have high cultural values for the traditional owners.

The Banbai Rangers are tackling weeds and feral animals on both properties. Some of the biggest challenges for managing weeds on the IPAs are the weather, difficulty in accessing weeds and trying to ensure that all weeds are being managed at once. Cattle have also brought new weeds into the IPAs.

Feral animals are managed through shooting, trapping and netting or line-catching fish. The Banbai community has put a lot of effort into controlling mosquitofish (*Gambusia affinis*). Mosquitofish have been associated with decline of native fish species. Since mosquitofish do not like cool water, the Banbai Rangers have planted 300 mat rush (*Lomandra* spp.) plants in riparian areas and erected shade cloth across the river to lower the water temperature. These sites are monitored once a week.

The Banbai community is also interested to see how fire affects weeds and feral animals. 'I think it would be interesting to find out what comes back, native or introduced, with the "right way" burn as opposed to the "wrong way" burn where we had to use a lot of chemicals to control the weeds afterwards', says Tanya Elone, manager of the Banbai Business Development Aboriginal Corporation. Banbai Rangers and a PhD student at the University of New England are developing a 2-way monitoring system using Indigenous and scientific knowledge to consider the effects that fire has on the environment.

Owning and managing Wattleridge and Tarriwa Kurrukun IPAs gives the Banbai community an opportunity to look after their Country and culture, and to pass it on to the next generations. Elder and ranger Lesley Patterson, believes 'our children need to know their culture and their Country so that they can keep themselves and their land healthy for generations to come'.

Feral cattle on the Coleman River floodplain, Cape York

Photo by Dan Metcalfe, CSIRO

Source: Tanya Elone and Travis Patterson (Banbai Enterprise Development Aboriginal Corporation), and Michelle McKemey (University of New England)

Indigenous fire management across northern Australia

Fire management is a crucial component of the wider management of the Australian landscape, enabling control of the timing, size and intensity of fires, and contributing to environmental management to preferentially encourage or inhibit particular species (see the *Biodiversity* report). Effective fire management sustains healthy landscapes and, where reductions in carbon emissions contribute to carbon markets, provides important Country-based income streams for Indigenous people (Russell-Smith et al. 2013).

Aboriginal fire practices have been described by researchers as 'patch mosaic burning' and early dry-season burning. The application of early dry-season patch burning in several northern Australian contexts (such as Arnhem Land and north Kimberley) has resulted in some beneficial outcomes for biodiversity, by protecting endangered tropical heathlands and habitat for small mammals (Murphy & Duncan 2015, Radford et al. 2015). It has also contributed to the abatement of greenhouse gas emissions. Early dry-season burning underpins prescribed burning to reduce the frequency and spread of high-intensity wildfires, and thereby lower greenhouse gas emissions, in northern Australia (Yates et al. 2008, Russell-Smith et al. 2013). Early dry-season burning in the savannas is also an effective tool to increase carbon sequestration in the debris pools, by ensuring that fires are smaller and less intense than late dry-season fires and consume less organic matter. Currently, southern Australia is not as amenable to the maximisation of carbon storage potential through fire management because of the much lower frequency of fire in the landscape, which limits the ability of fire management to impact on unplanned fire activity. However, fire management will become increasingly important for biodiversity conservation as the climate warms (Bradshaw et al. 2013).

Indigenous people's own view of their fire management practices emphasises linkages between customary law, economies, social relations, ecology and the application of management activities in response to cues such as seasonal indicators (Bright 1995, Rose 1995, Hill et al. 1999). The description of Indigenous fire as just 'patch mosaic burning' ignores these culturally embedded mediating and explanatory factors, meanings and purposes (Bright 1995; Hill et al. 2004, 2008).

One important means by which Indigenous fire knowledge and management can be formally recognised is through conservation agreements. However, recognition under these agreements does not always successfully incorporate fire knowledge, or empower Indigenous holders of fire knowledge and fire managers. This is also evident in carbon abatement programs. Economic benefits to Indigenous people from carbon markets and associated schemes involving 'payment for ecosystem services' allow Indigenous landholders and managers to achieve environmental goals. The development of carbon sequestration and abatement projects also generates co-benefits such as reconnection with Country and other cultural benefits (Howe et al. 2014). In practice, however, designing carbon offset programs and policies that achieve both carbon benefits and associated co-benefits has proved challenging; in some cases, separate programs fund biodiversity, social and cultural benefits without carbon abatement occurring (Reed 2011, Gerrard 2012, Robinson et al. 2016b). Efforts have been frustrated both by a lack of understanding about the value to communities and the parameters under which benefits for Indigenous communities can be sought, and by the realisation that there may be fewer opportunities than anticipated to simultaneously realise a full suite of carbon and Indigenous co-benefits (Robinson et al. 2014).

The challenges to the incorporation of Indigenous fire knowledge into contemporary fire management can be cultural, reflecting differences in world views; institutional, reflecting constraints in how the programs are conceptualised; scientific, reflecting the availability of data that support the knowledge; and logistical and operational, reflecting limits to the resources available to complete the work. Ongoing refinements in our understanding of the role that fire plays in driving community, landscape and global processes also mean that there may be a need to refine fire management practices. Sometimes it may not be appropriate to incorporate past Indigenous practices into modern fire management.

Wind turbines at Codrington Wind Farm generating electricity on the coastal headlands at sunset near Yambuk in Victoria

Photo by Arthur Mostead

Assessment summary 8
Effectiveness of land management

Summary	Assessment grade: Ineffective	Partially effective	Effective	Very effective	Confidence: In grade	In trend	Comparability: To 2011 assessment
Climate-induced pressures							
Understanding: The general nature and pattern of climate-induced pressures have become clearer, although revised funding priorities suggest that adaptation research will become a greater focus than improving basic understanding							
Planning: Modelling to inform planning decisions is increasingly advanced in some areas. Plans to support climate change adaptation, such as supplementing the protected area estate, are becoming increasingly sophisticated							
Inputs: Substantial initial investments have been made in national-scale and state-scale research on likely impacts and possible management responses							
Processes: National and state bodies, and industry sectors continue to engage with the issue of climate change. However, there remains a lack of consensus at the highest political levels about strategies to mitigate climate change or adapt to its consequences							
Outputs and outcomes: Outputs continue to focus primarily on the knowledge and information base necessary to inform management responses, but a growing number of practical actions are being implemented							

Assessment summary 8 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Bushfire				
Understanding: There is a generally high level of understanding of the impacts of bushfires on environmental values, and an increasing recognition that some approaches to risk mitigation for life and property have negative environmental impacts, which is leading to novel management solutions	Effective ↗	●	●	◆
Planning: Generally, there is a high level of planning for bushfire management, for both risk mitigation and improving environmental consequences of bushfires	Effective ↗	●	●	◆
Inputs: Although inputs for bushfire risk mitigation and management have increased, particularly for public land in southern Australia, funding is insufficient to manage the impacts of bushfire on environmental values	Partially effective —	●	●	⬙
Processes: There are well-developed processes for evaluating the impacts of bushfire management strategies on environmental values, and for adaptive management	Very effective —	●	●	◆
Outputs and outcomes: In general, the greater recognition and understanding of the positive and negative impacts of bushfires mean that management approaches are increasingly considering the full range of consequences before action is initiated	Effective ↗	●	●	⬙

Assessment summary 8 (continued)

Summary	Assessment grade	Confidence	Comparability
	Ineffective / Partially effective / Effective / Very effective	In grade / In trend	To 2011 assessment

Land clearing

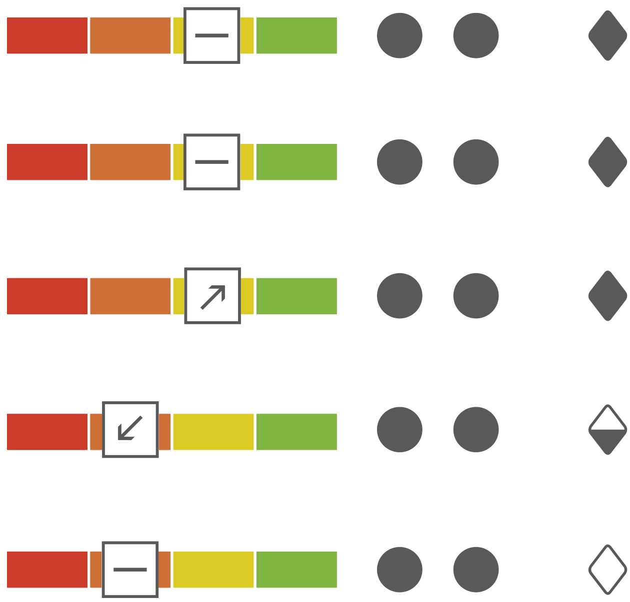
Understanding: Impacts of land clearing on environmental values are well understood

Planning: All states and territories, other than the Northern Territory, where legislation is now being enacted, have legislation to control land clearing

Inputs: The availability and quality of monitoring and reporting systems and tools are key inputs; these continue to be improved nationally and within jurisdictions

Processes: Processes vary between jurisdictions; there have been reversals in legislative control of land clearing in some jurisdictions

Outputs and outcomes: Land clearing continues to threaten environmental values in some areas, as a consequence of ongoing clearing and cumulative impacts of other threatening process on fragmented habitat



Assessment summary 8 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Invasive species				
Understanding: Well-established, coordinated national arrangements exist for identification of, minimisation of, and response to, biosecurity risks. National, and state and territory strategies are in place for managing priority pest animal and invasive plant species	Effective —	●	●	◆
Planning: High levels of national, state and territory, and regional-level planning exist for priority invasive species	Effective —	●	●	◆
Inputs: Significant financial inputs from Australian, state and territory, and local governments are highly targeted, but the scale of the threats, the diversity of opinions about prioritisation, and the range of impacts an invasive species may have (depending on the environmental context) mean that, inevitably, some important impacts are not adequately resourced. Private landholders and communities also make major contributions to managing invasive species at local levels	Partially effective ↗	●	●	◆
Processes: Management processes vary widely, depending on the nature of the invasive species or threat. Processes are public, and stakeholders are appropriately engaged. An ongoing challenge is that resources are often tied to formal risk categorisation, which means that eradication opportunities may be missed as new incursions become well established before effective management can begin	Effective —	●	●	◆
Outputs and outcomes: The success of strategies for individual invasive species varies, both spatially and temporally. However, overall, invasive species are expected to become more, rather than less, threatening for land environmental values	Partially effective ↙	●	●	◆

Assessment summary 8 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective); Confidence (In grade / In trend); Comparability (To 2011 assessment)
Management of conservation reserves	
Understanding: The objectives of the National Reserve System, and for management of conservation reserves, are explicitly specified in national, and state and territory policy statements, and in management plans	
Planning: Management plans are the basis of planning for individual reserves. Incorporation of data to underpin the decision-making processes is improving, and scenario planning approaches are engaging with community expectations	
Inputs: Despite considerable investment, resource inputs across the whole conservation system are insufficient for management objectives to be realised, especially as the likely effects of climate change become better understood	
Processes: Processes governing management of conservation reserves are generally clear and transparent, draw on stakeholder input, and report to stakeholders. However, legislative challenge to reserve integrity suggests that these processes are not necessarily stable	
Outputs and outcomes: Short-term management outcomes are usually achieved, but longer-term aspirational outcomes will require ongoing attention to management of threatening processes	

Assessment summary 8 (continued)

Summary	Assessment grade: Ineffective	Assessment grade: Partially effective	Assessment grade: Effective	Assessment grade: Very effective	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Indigenous-managed lands							
Understanding: Indigenous land managers consider the sector to be highly politicised, confusing and bureaucratic. Greater recognition of traditional knowledge and its applications to land management are improving both engagement and outcomes in many areas		—			●	●	◆
Planning: Greater Indigenous input at early stages of planning, and wider use of Indigenous reference groups for major projects and programs are ensuring that, in many regions, Indigenous representation is more meaningful and more powerful. There is still room for improvement		—			●	●	◆
Inputs: Continued investments by governments and the transition to a fee-for-service model enable many successful Indigenous management units to function successfully. Short-term fluctuations in funding availability and competing demands for skilled workers mean that staff turnover can be an issue in some regions		—			●	●	◆
Processes: There are ongoing challenges associated with short-term project funding and mandatory reporting on issues that have limited or no local cultural relevance		—			●	●	◆
Outputs and outcomes: Some Indigenous groups are having significant impacts in improving land management within their regions. In other regions, competing interests, inconsistent funding or lack of capacity are restricting impact		↗			●	●	◆

Assessment summary 8 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Production forests				
Understanding: Native forest management is regulated in all states and territories by legislation. Plantations are also regulated in most states. Many plantation owners have obtained independent certification	Very effective —	●	●	◆
Planning: Management plans are required in most jurisdictions	Very effective —	●	●	◆
Inputs: Commercial investment in production forestry has declined, putting the industry at risk	Effective ↙	●	●	⬙
Processes: Levels of stakeholder engagement in management of public forests are high	Effective —	●	●	◆
Outputs and outcomes: Outputs are typically assessed against commercial objectives, and these have been declining. Outcomes are assessed against certification and legislative requirements	Effective —	●	●	⬙
Grazing lands				
Understanding: There is good understanding of grazing practices, and land management practices associated with best-practice management	Effective ↗	●	●	⬙
Planning: Property planning is routinely of a good standard, including positive engagement with best-practice proposals	Effective ↗	●	●	⬙
Inputs: Funding declines mean that long-term monitoring has largely ceased	Effective ↙	●	●	⬙
Processes: Improved through industry and agency support, but reduced funding and a challenging financial environment mean that best practice is not fully implemented	Effective —	●	●	⬙
Outputs and outcomes: Legacy of degradation through overgrazing and drought years means that, although progress is steady, some outcomes are still suboptimal	Effective —	●	●	⬙

Assessment summary 8 (continued)

Summary	Assessment grade: Ineffective / Partially effective / Effective / Very effective	Confidence: In grade / In trend	Comparability: To 2011 assessment

Dryland cropping

Understanding: Understanding of how to improve management for the least environmental impact is improving

Planning: Improved forecasting and cropping models support farm planning

Inputs: Reduced investments mean that environmental efficiencies are not routinely achieved

Processes: Reduced investments in research and changes to extension services

Outputs and outcomes: Ongoing contribution to exported sediment loads and salinity is decreasing through management, but still significant

Irrigation and intensive agriculture

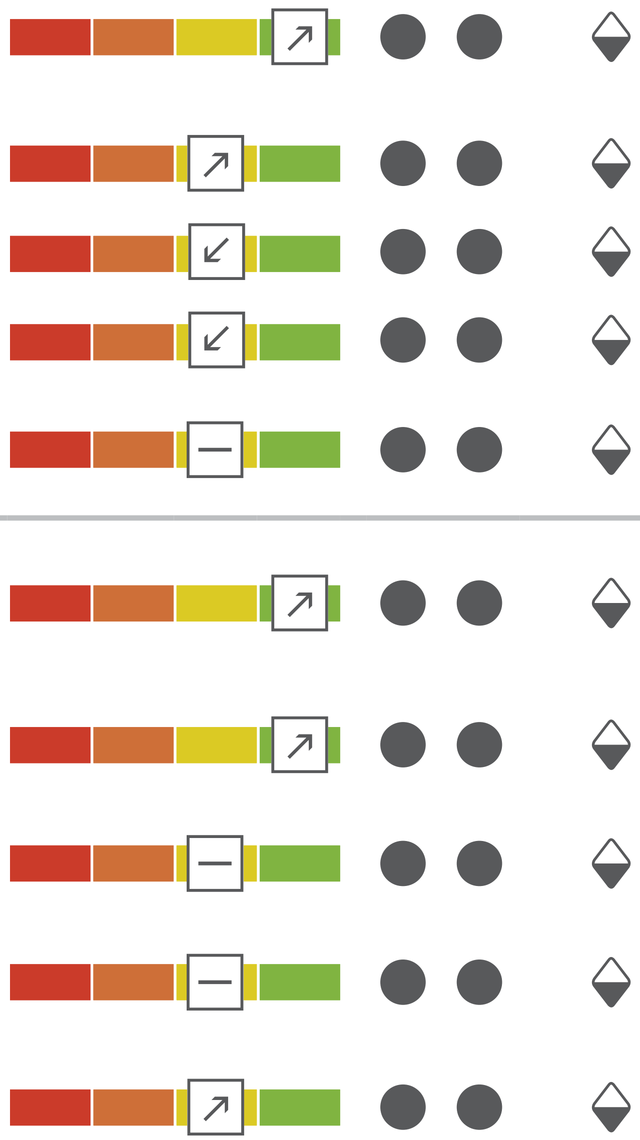
Understanding: There is good understanding of best-practice management, and models suggest that this is being implemented

Planning: There is good understanding of best-practice management, and models suggest that this is being implemented

Inputs: Investments in research and development from multiple sources are increasing adaptive management capacity

Processes: There are some indications that best practice is not being fully implemented because of changes in extension services

Outputs and outcomes: Still a major source of sediment and chemicals in run-off, but significant improvements apparent



Assessment summary 8 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Mining				
Understanding: Understanding of impacts has improved, and work is under way to ensure that all stakeholders are aware of impacts and their mitigation	Very effective ↗	●	●	⬙
Planning: There is significant investment in bioregional assessments, and state and territory work to plan for shale gas	Very effective ↗	●	●	⬙
Inputs: Commercial investment in the sector has decreased, but government inputs to ensure clear understanding of costs and benefits have increased	Effective —	●	●	⬙
Processes: Statutory requirements are in place for management and monitoring, and for approvals phase. Insufficient emphasis on rehabilitation	Effective —	●	●	◆
Outputs and outcomes: Significantly improved, although shortfall in investment for rehabilitation will provide a regrettable legacy	Effective —	●	●	◆
Urban and residential use				
Understanding: There is a clear understanding of the impacts of urban development, and growing research into sustainable urban design	Effective ↗	●	●	◆
Planning: Innovative design to improve urban environments is not consistently taken up; short-term perspectives are leading to increasing challenges associated with modelled consequences of anticipated sea level rise	Effective —	●	●	⬙
Inputs: Large private-sector investment is leading to oversupply	Effective —	●	●	◆
Processes: Sensitive planning design is not routinely implemented	Effective —	●	●	◆
Outputs and outcomes: Alienation of agricultural land and native vegetation continues, with limited evidence of major change in approaches to development	Effective —	●	●	⬙

Assessment summary 8 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Waste disposal				
Understanding: Impacts are clearly understood. Innovative approaches to use recycled products are in progress	Very effective ↗	Adequate	Adequate	Somewhat comparable
Planning: Continued improvement is needed as landfill sites close. Ongoing investment in preventing, rather than disposing of, waste is required	Effective —	Adequate	Adequate	Somewhat comparable
Inputs: There is increasing private investment in waste management and recycling, and significant public engagement	Effective —	Adequate	Adequate	Somewhat comparable
Processes: Legislative control is in place at all levels. Monitoring is not adequate at all landfill sites	Effective —	Adequate	Adequate	Somewhat comparable
Outputs and outcomes: Continued improvement	Very effective ↗	Adequate	Adequate	Somewhat comparable

For additional information and an accessible version of the assessment summary, see SoE Digital.

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Grades

- **Very effective:** Understanding of environmental and cultural systems, and factors affecting them is good for most management issues
- **Effective:** Understanding of environmental and cultural systems, and factors affecting them is generally good, but there is some variability across management issues
- **Partially effective:** Understanding of environmental and cultural systems, and factors affecting them is only fair for most management issues
- **Ineffective:** Understanding of environmental and cultural systems, and factors affecting them is poor for most management issues

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Assessment summary 8 (continued)

Elements of management effectiveness and assessment criteria	Grades
Management context (understanding of environmental issues; adequacy of regulatory control mechanisms and policy coverage)	
Understanding of context Decision-makers and environmental managers have a good understanding of: • environmental and socio-economic significance of environmental values, including ecosystem functions and cultural importance • current and emerging threats to values. Environmental considerations and information have a significant impact on national policy decisions across the broad range of government responsibilities	**Very effective:** Understanding of environmental and cultural systems, and factors affecting them is good for most management issues **Effective:** Understanding of environmental and cultural systems, and factors affecting them is generally good, but there is some variability across management issues **Partially effective:** Understanding of environmental and cultural systems, and factors affecting them is only fair for most management issues **Ineffective:** Understanding of environmental and cultural systems, and factors affecting them is poor for most management issues
Planning Policies and plans are in place that provide clarity on: • objectives for management actions that address major pressures and risks to environmental values • roles and responsibilities for managing environmental issues • operational procedures, and a framework for integration and consistency of planning and management across sectors and jurisdictions	**Very effective:** Effective legislation, policies and plans are in place for addressing all or most significant issues. Policies and plans clearly establish management objectives and operations targeted at major risks. Responsibility for managing issues is clearly and appropriately allocated **Effective:** Effective legislation, policies and plans are in place, and management responsibilities are allocated appropriately, for addressing many significant issues. Policies and plans clearly establish management objectives and priorities for addressing major risks, but may not specify implementation procedures **Partially effective:** Legislation, policies and planning systems are deficient, and/or there is lack of clarity about who has management responsibility, for several significant issues **Ineffective:** Legislation, policies and planning systems have not been developed to address significant issues
Management capacity (adequacy of resources, appropriateness of governance arrangements and efficiency of management processes)	
Inputs Resources are available to implement plans and policies, including: • financial resources • human resources • information	**Very effective:** Financial and staffing resources are largely adequate to address management issues. Biophysical and socio-economic information is available to inform management decisions **Effective:** Financial and staffing resources are mostly adequate to address management issues, but may not be secure. Biophysical and socio-economic information is available to inform decisions, although there may be deficiencies in some areas **Partially effective:** Financial and staffing resources are unable to address management issues in some important areas. Biophysical and socio-economic information is available to inform management decisions, although there are significant deficiencies in some areas **Ineffective:** Financial and staffing resources are unable to address management issues in many areas. Biophysical and socio-economic information to support decisions is deficient in many areas

Assessment summary 8 (continued)

Processes A governance system is in place that provides for: • appropriate stakeholder engagement in decisions and implementation of management activities • adaptive management for longer-term initiatives • transparency and accountability	**Very effective:** Well-designed management systems are being implemented for effective delivery of planned management actions, including clear governance arrangements, appropriate stakeholder engagement, active adaptive management and adequate reporting against goals **Effective:** Well-designed management systems are in place, but are not yet being fully implemented **Partially effective:** Management systems provide some guidance, but are not consistently delivering on implementation of management actions, stakeholder engagement, adaptive management or reporting **Ineffective:** Adequate management systems are not in place. Lack of consistency and integration of management activities across jurisdictions is a problem for many issues
Achievements (delivery of expected products, services and impacts)	
Elements of management effectiveness and assessment criteria	**Grades**
Outputs Management objectives are being met with regard to: • timely delivery of products and services • reduction of current pressures and emerging risks to environmental values	**Very effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are being demonstrably reduced **Effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are understood, and measures are in place to manage them **Partially effective:** Management responses are progressing and showing signs of achieving some objectives. Targeted threats are understood, and measures are being developed to manage them **Ineffective:** Management responses are either not progressing in accordance with planned programs (significant delays or incomplete actions) or the actions undertaken are not achieving their objectives. Threats are not actively being addressed
Outcomes Management objectives are being met with regard to improvements to resilience of environmental values	**Very effective:** Resilience of environmental values is being maintained or improving. Values are considered secured against known threats **Effective:** Resilience of environmental values is improving, but threats remain as significant factors affecting environmental systems **Partially effective:** The expected impacts of management measures on improving resilience of environmental values are yet to be seen. Managed threats remain as significant factors influencing environmental systems **Ineffective:** Resilience of environmental values is still low or continuing to decline. Unmitigated threats remain as significant factors influencing environmental systems

Resilience

of the land environment

At a glance

Australian landscapes have evolved with soils and vegetation in equilibrium with the climate and natural disturbance regime. Land management activities disturb that equilibrium. Although we may not see all of the ensuing changes, the subtle and slowly accumulating ones can be the most significant in terms of altering the future supply of resources and services from the land.

Resilient land should be able to recover from changes, and continue to support native vegetation and natural processes, as well as allow us to use natural resources within reasonable limits. A challenge for Australians is to decide how much to demand of the ancient and complex Australian land environments without destroying them.

Native species and ecological communities have evolved to cope with, and sometimes heal, the effects of natural disturbance events. If too much native vegetation is cleared and too much of the soil microbiota is lost, the chances of recovery are compromised. Australian land managers are improving their understanding of how to retain resilience, although in some cases this requires active rehabilitation of landscapes or ecological communities. Improved collaborative approaches to managing the whole of the Australian environment are needed to retain or rebuild the resilience that will be needed to cope with future pressures.

The resilience of Australia's land, soil and vegetation can be assessed in 2 stages: first, in terms of the interaction of land with land use and the maintenance of environmental values under particular land-use regimes; and second, in terms of how well land regains these values after major disturbances such as clearing, flood or fire.

Landscape and soil

Under natural conditions, the land (i.e. landforms, soils, drainage networks of streams and rivers, vegetation and other biota) is in some sort of equilibrium with the climate and disturbance factors such as bushfire. This equilibrium is disturbed by land management, because changed practices can occur faster than the land's ability to respond and achieve a new equilibrium. As a result, the land is in a constant state of change. Whereas some changes may be acute, such as landslides, most changes are chronic, such as slow acidification of soil, gradual habitat change and low levels of sediment loss. These chronic changes may pass unnoticed, can be difficult to monitor, and often pose the greatest challenge to land managers.

Resilient land should provide a long-term, optimal mix of ecosystem services, relative to its environmental context. In general, good-quality and resilient land has these related features:

- Nutrient levels are maintained, with neither significant nutrient depletion nor nutrification taking place.
- Biological production is high relative to the potential limits set by climate.
- Levels of biodiversity are relatively high.
- Rates of soil erosion and deposition are low, with only small quantities of soil transferred out of the system (e.g. to the marine environment).
- Contaminants are not introduced into the landscape, and existing contaminants are not concentrated to levels that cause harm.
- Systems for producing food and fibre for human use do not rely on large net inputs of energy, either directly through physical management or indirectly through the addition of agrichemicals.

At the heart of the resilience question is how we manage the land and its assets. Significant land management issues that will have major consequences for current and future land resilience include the following:

- How do we increase agricultural productivity without destroying the provision of ecosystem services that we also rely on?
- How do we resolve the competition for access to land between agriculture and the resources sectors; urban development and infrastructure provision; and environmental stewardship, cultural and recreational needs?
- In a changing world, how do we maintain or increase natural resilience to enable the land to equilibrate to new climates while preserving the biodiversity, productivity and ecosystem services that we desire?

Agricultural productivity can be increased by increasing the productivity of existing agricultural practices, or by expanding the area under agriculture. Increasing productivity typically means intensification, which usually means increased inputs of nutrients, pesticides, time and other resources. Increased productivity can also be achieved through increased efficiencies, such as better targeted inputs, both in time and space, to improve their impact, and better conversion of resources into desirable products, such as milk, grain, meat and fruit. Improved targeting should also mean reduced loss of nutrients and wastage of pesticides. In a continent with naturally poor soils, nutrification can significantly change recruitment dynamics, favouring exotic grasses over native species (Duncan et al. 2008). Nutrient run-off is still a significant threat to the Great Barrier Reef (Queensland Government 2013) and inland waterways (see the *Inland water* report). However, whereas the risks posed by insufficient nutrient addition are borne by the farmer concerned, the risks posed by overapplication and run-off of nutrients are often felt downstream of application. For example, there is a trend towards increasing application of nitrogen in cotton in irrigated systems, which increases the potential for movement of fertiliser offsite (Braunack 2013). There are also anecdotal suggestions that some cane farmers are routinely applying fertilisers at above recommended rates, 'just in case'. This suggests that the way in which we perceive and discuss risk needs to be refined.

Competition for land does not of itself affect landscape resilience, but the consequences of different land management options can. While some land uses—for example open-cut mining and intensive agriculture—are mutually exclusive at the same point in the landscape, resilience can be increased through creative thinking about associated landscape features. Thus, it is possible to protect and conserve the resilience of natural systems in parallel with different land uses—for example, through sensitive management of natural environments within mining tenements and urban areas.

Maintaining the natural resilience of the landscape, and increasing resilience against future climate change, sea level rise and extreme events require improved understanding of what determines resilience today. There is a good understanding of the physical and chemical nature of our soils, and their distribution, but there is a very poor understanding of soil biology and the function of soil microbial communities, in particular. It is known neither to what extent the resilience of natural and even agricultural soils is mediated by microbes, nor whether the current degradation of this community is ongoing or especially threatened by climate change. The BASE project—Biomes of Australian Soil Environments (Bissett et al. 2016)—is a collaborative, proof-of-concept project to generate a national framework dataset of Australian soil microbial communities. This will go some way to highlighting the paucity of our knowledge, but considerably more work will be required to understand how the microbiota interact with each other, with plants and with the environment.

Vegetation

The resilience of vegetation is largely determined by our success or failure in maintaining resilience in landscapes and soils, as discussed in the Landscape and soil section. Maintenance of vegetation is both a factor in and a consequence of maintaining resilience in the rest of the biodiversity of a region. The resilience of vegetation to change depends on the extent to which essential ecological processes are maintained.

Resilience is greatest in areas where vegetation is largely intact, or where extensive patches of largely intact native vegetation are continuous or at least contiguous, so that connectivity is maintained between them for the movement of animals, seeds, pollen and other disseminules. In such areas, if disturbance is at levels consistent with background environmental processes and at an appropriate scale relative to the remnants, native vegetation and the communities dependent on it are reasonably resilient. These areas include land managed for conservation, and large areas of remote Australia; however, even here, unnatural disturbance—such as bushfires at a higher frequency or intensity, or the effects of feral animals (see Pressures affecting the land environment)—can dramatically reduce resilience.

In areas where connectivity is poor, or where dispersal is limited by lack of appropriate animal vectors, proactive restoration may be necessary to rebuild resilience. A National Wildlife Corridors Plan was announced in 2012 to help link protected areas and facilitate movement of animals in response to changing climate, but this plan ceased in 2014 after funding reductions. Activities that support or increase connectivity are still funded through the National Landcare Programme, and through state and territory funding, but not in the coordinated way that was envisaged. The private sector, community groups and nongovernment organisations play a very significant role in active rehabilitation of landscape.

Landscape resilience is also being supported through a diversification of the land managers with responsibility for natural and production landscapes, ensuring that a variety of experience and perspectives are available. Increases in opportunities for Indigenous rangers to incorporate traditional ecological knowledge in management of Country help build cultural and community resilience, as well as increasing environmental resilience. Better sharing of monitoring data, cultural understandings, scientific best practice and management experience is needed to ensure that all perspectives and information are available as we make challenging decisions about future land management in environmental contexts we are not familiar with.

Wildfire in coastal vine thicket, Pormpuraaw, Cape York, Queensland
Photo by Dan Metcalfe, CSIRO

Risks
to the land environment

At a glance

The predicted impacts of climate change pose the greatest risks to Australia's land environment. These impacts include changes in the distribution and success of native species and ecosystems; the viability of some agricultural enterprises; and the impact of natural processes and events, such as extreme weather, with consequent impacts on environmental processes and function.

Inadequate investment in monitoring change, and in developing and instituting appropriate management responses, poses a significant risk that we will be unable to prevent, reduce or adapt to both current and future challenges.

The risks facing the land environment in 2016 are essentially those that have been identified in previous SoE reports. Risks reflect the conjunction of the legacy of past management decisions, contemporary actions, and expected pressures in particular regions and locations. Some of these risks are well known, whereas others, such as the impacts of sea level rise and climate change, are much modelled but not fully understood or anticipated. CSIRO's assessment of global megatrends (Hajkowicz et al. 2012)—the significant shifts in environmental, economic and social conditions that will play out over the coming decades—suggests that we should be especially aware of the increasing demand that a global population has for energy, food, water and mineral resources, and the consequent decline in the world's natural habitats and species. Many of the risks identified for land are directly related to these global megatrends.

Modified floodplain of the Barron River near Cairns—drainage, vegetation clearance and fragmentation, urban infrastructure development, and rain-fed agriculture

Photo by Dan Metcalfe, CSIRO

Assessment summary 9

Current and emerging risks to the land environment

	Catastrophic	Major	Moderate	Minor	Insignificant
Almost certain		Native vegetation extent and connectivity continue to decline Climate change leads to new diseases, pests and weeds	Run-off from managed land irreversibly damages parts of aquatic and marine systems before it can be sufficiently reduced		
Likely		Native species are no longer adapted to the climate envelopes in which they find themselves Widespread acidification of agricultural lands occurs	Heat stress becomes of increasing concern in agriculture Cumulative impacts occur on species and communities from multiple stressors at multiple locations		
Possible		Inadequate investment leads to reduced scientific and management capacity to respond to emerging issues	Climate change exacerbates competition between industries and sectors for available land Coastal inundation affects the viability of some agricultural land, urban land and native vegetation		
Unlikely					
Rare					

Not considered

Outlook
for the land environment

At a glance

The outlook for Australia's land environment is shaped by the legacy of our former activities, the current and future pressures on the land environment, and how we respond to these pressures.

The many consequences of climate change provide the greatest challenges. The challenges include understanding how to facilitate resilience in already depleted natural communities; ensuring food and energy security; and managing conflicts for the use of land, and trade-offs between different sectors of the economy and different human communities, in a context of change in many other areas, as discussed in other themes.

Other challenges include the threats posed by invasive species; maintaining agricultural productivity as well as environmental sustainability; and balancing the demands of a growing, and increasing urban, population with the economic necessity of a viable resources sector.

The development of more national, rather than regional or local, perspectives and strategies is an important step in ensuring that decisions are taken at an appropriate scale, while recognising the critical need for local and regional information and perspectives to underpin national decisions. It is hard to see that decisions are currently being made at an appropriate temporal scale.

The outlook for Australia's land environment is determined by its current state, the pressures affecting it, its resilience to these pressures, and our effectiveness in managing the pressures and facilitating landscape resilience. These areas have all been discussed in this report, but are also co-dependent on pressures and responses discussed in the *Drivers* report, and in linked themes, including *Biodiversity*, *Inland water*, *Atmosphere* and the *Built environment*.

Concerted efforts will need to be made in several areas to ensure that the land is able to continue to provide us with the resources and services that we rely on. Many of these issues have been highlighted in previous SoE reports, but continue to pose very real risks in the medium term.

Climate change is discussed in the *Atmosphere* report and is raised in all other themes, but potentially has some specific impacts on the land environment. This is currently focusing attention on possible management actions that may help reduce climate change impacts, increase system resilience or allow us to adapt to the consequences. For example, modelling suggests that many native species will not be able to survive in their current locations as the climate changes (Costion et al. 2015, Reside et al. 2016). As a consequence, some species are likely to face extinction, while others may move across the landscape, assuming that sufficient connectivity exists to facilitate this movement. Novel combinations of native species will occur as current range boundaries extend or shrink; in some of these novel communities, exotic species may actually enhance resilience, bridging gaps in plant and animal lifecycles (Aizen et al. 2008). Climate change will also affect the distributions of diseases, pests and weeds. Although some of these will become less threatening, new incursions are likely, and species and diseases that are currently constrained to particular areas or habitats may have the potential to extend their range or impact. In agriculture, drought will remain the dominant climatic challenge, but heat stress will increase. Some regions will see the mix of potential agricultural options change, and much land that is currently only marginally viable for agricultural enterprises will have to undergo a complete change in management or become nonviable (Howden et al. 2014).

Climate change is also altering the timing and duration of fire weather. Indications are that bushfires are likely to become even more threatening to life, property and the environment as extreme weather conditions become more frequent. The challenge of managing bushfires for the often conflicting demands of environmental purposes, or to protect infrastructure and housing, or to maximise carbon sequestration, will thus become more acute.

Ongoing clearing of native vegetation, particularly of regrowth now that most remnant old-growth vegetation is protected, means that legacy issues of historical vegetation clearance are not being addressed. As well, clearing means that the consequences of poor connectivity are maintained or exacerbated—for example, increased habitat for weeds and pest species, declines in native species, and reduced landscape resilience. Land clearing in coastal catchments is likely to increase erosion and sediment run-off, which is of particular concern for the Great Barrier Reef.

Other land management activities, such as mining, horticulture and cropping, are responsible for most of the nutrients, sediments and pesticides entering water bodies and ultimately the sea (Bartley et al. 2012). Modelling of current best-practice management suggests that contaminant loads in run-off are decreasing, but that they are still sufficiently high that they continue to have damaging impacts offshore, such as on the Great Barrier Reef (Brodie et al. 2013), and inland, such as in the Murray–Darling system (Holland et al. 2015).

One potential solution is to objectively assess the risks and benefits associated with more marginal land, and take the least viable land out of production, instead focusing on increasing production efficiencies on the best land. Similarly, a medium-term view might also consider those coastal areas most susceptible to flooding through sea level change, and whether managed retreat, rehabilitation of protective native vegetation buffers and enhanced protection for more elevated areas might make economic and environmental sense. There are already some instances of reclaimed saltmarsh, identified as unproductive agricultural land, being zoned for urban development; this could lead to trouble in the future because sea level rise will potentially inundate these areas.

Conflicting demands for land are likely to continue, with mining and the resources sector, farming and forestry systems, urban and infrastructure development, and land for offsets, set-aside land and buffers competing for space with the conservation estate and protection of natural systems. Each of these uses can make positive and negative contributions to the economic, social, cultural and environmental development of Australia. Although land use is often dealt with at a local level, national and even international perspectives are also relevant and often highly pertinent (Hajkowicz et al. 2012). Spatial land-use planning may help us understand and resolve these conflicts for efficient landscape management (Bryan et al. 2016). However, climate change may exacerbate this competition, as our demands change, as use of some land for agriculture or forestry becomes less feasible, and as competing demand for other primary production sectors—such as plantings for carbon offsets and carbon sequestration—expand.

Urban expansion competes for land space, affects a range of environmental processes and services, and requires substantial investment to deal with provisioning and waste services, and infrastructure maintenance. Huge steps have been made in reducing the waste stream and increasing recycling, but there are still some very large challenges to overcome in further reducing the waste stream, and developing in-country recycling capability. Continued population movement from rural and regional areas to capital cities and large metropolitan areas exacerbates these challenges, and also denudes rural areas of people, reducing community viability and resilience.

Concerns about global food security and the consequences for Australia, where most agricultural production is for export, are likely to grow (Qureshi et al. 2013). This will have consequences for expansion and intensification (Hochman et al. 2013) of the agriculture sector. The current interest in developing northern Australia is the latest in several attempts over 170 years (Cook 2009). It has broad political and community support, and for the first time is also engaging Indigenous communities in the debate in a meaningful way (Box LAN15). Consequently, it is vital for environmental scientists with relevant contextual experience to engage in the process to ensure that any development is truly sustainable, and any consequences of development are minimised. This aspiration may prove challenging after iterative declines in research funding across northern Australia, especially for research into the management of the tropical savannas and more southern arid landscape, risks of degradation to the long-term resource base, and consequent loss of ecological function and economic potential. Governments and industries are investing in assessments of soil suitability, water availability, crop improvements and infrastructure upgrades, which are likely to significantly increase the chances of success.

Affecting both the natural environment and managed agricultural and silvicultural environments, invasive species have potentially transformative effects. Establishment of a new disease, pest or pathogen that has the potential to significantly affect an agricultural industry, or cause major change in ecological function or environmental processes, could have major consequences. Hypothetical examples include a nationwide incursion of an exotic fruit fly that devastates a number of fruit and vegetable crops, a nationwide outbreak of a disease such as foot-and-mouth disease or clinical bluetongue, or the emergence of a highly virulent pathogen that affects native vegetation (Simpson & Srinivasan 2014). Advances in the use of biocontrol, and the integration of biocontrol and chemical control approaches are in part stimulated by the ongoing emergence of pesticide tolerance, but also by environmental considerations. New biocontrol agents (such as rabbit haemorrhagic disease virus) may be able to reduce the impact and costs associated with control of major pests. Developments in synthetic biology, through either transgenic approaches or selecting favourable natural alleles, offer conceptual solutions that may be currently unacceptable to regulators or the general public. An example is the use of 'daughterless' technologies to change the sex ratio of the progeny of invasive rodents and help drive them to extinction (Campbell et al. 2015).

Increasingly strong collaborative, national initiatives aim to combat invasive species, understand the national forest resource, protect our critical biodiversity, and target investments that will have national benefits. These approaches should ensure that decisions are taken at an appropriate scale to deal with increasingly national problems. Ongoing investment, consultation and monitoring at regional scales are critical to ensuring that decisions are made with the best information possible. A huge remaining challenge is to ensure that decisions are also made at the appropriate temporal scale. Initiatives that are announced with fanfare but closed down within years lead to wasted resources and opportunities in managing long-term environmental issues. Short-term projects do not support stable careers in land management, and the loss of skilled workers from ranger groups to industry sectors, declines in research and management staffing, and reduced university intakes in relevant disciplines will pose challenges to Australia's ability to respond to emerging environmental issues.

Box LAN15 Developing the north

Strong engagement with Indigenous communities in developing northern Australia (Australian Government 2015c) is crucial, in light of the increasing number of formal agreements and rights these communities are establishing on land and water; their presence on, and connection and responsibilities to, Country; their presence outside major urban centres; and the importance of their role in biocultural diversity. The white paper on developing northern Australia (Australian Government 2015c) presents new opportunities for engagement with Indigenous groups, who hold diverse formal land-use agreements and rights over at least 50 per cent of the region. Indigenous groups are also well placed to monitor and reduce biosecurity risks across the region—including incursions of exotic species, spread of pathogens and vectors, and landings by illegal foreign fishing vessels and other vessels that may carry pests or pathogens—and to conduct strategic weed and feral animal management (Marley 2007). However, they are unlikely to be able to reduce risks that come from external sources (e.g. increased movement of vehicles and goods).

Indigenous people represent 14.7 per cent of the population of northern Australia (Table LAN7) but a higher proportion of the population in the very remote areas (an average of 32 per cent) and in areas that are identified as Indigenous land interests (an average of 25 per cent) (see Figure LAN34). Indigenous people in these regions rely extensively on wild resources for food, culture, small enterprise and medicine (Jackson et al. 2012, Scheepers & Jackson 2012).

Box LAN15 (continued)

These remote communities face challenges as a result of distance, including limited transport and infrastructure, limited accessibility in the wet season, limited institutional capacity, and constrained opportunities for enterprise development and employment (Jackson et al. 2012, Altman & Markham 2014, Woinarski et al. 2014b). Although income generation opportunities through pastoral leases, cattle farming, and small enterprises such as fisheries, bushfood and tourism are increasing, protection and provision of ecosystem services is a major and undervalued activity in these regions.

Three catchments—the Mitchell, Darwin and Fitzroy—have been identified in the northern Australia development agenda. Water bodies in these catchments are integral to present-day Indigenous livelihoods, and can potentially sustain future water-related enterprises and employment (Scheepers & Jackson 2012). Indigenous people in the Mitchell catchment make up more than 90 per cent of the population on Aboriginal freehold lands, which occupy more than 10 per cent of the catchment area. The main formal mechanism of Indigenous involvement in land management in the Mitchell catchment is Indigenous Land Use Agreements (ILUAs). ILUAs occur in more than 60 per cent of the catchment, where grazing is the main land use. With only 9.5 per cent of the land under exclusive native title possession and more than 90 per cent of the region nationally categorised as very remote, conditions to support greater presence and economic independence of traditional owners on Country are limited.

Indigenous lands in the Darwin and Fitzroy basins are rich in culture, and represent some of the most intact and least disturbed areas in Australia. More than 90 per cent of both catchments are categorised as remote and very remote. Indigenous land interests in the Darwin catchment occur on 31.3 per cent of the catchment. Significantly, Indigenous people make up more than half the population on these lands (55 per cent), and Aboriginal language is still spoken by much of the population. ILUAs occur in less than 3 per cent of the catchment and are in place in important wetlands.

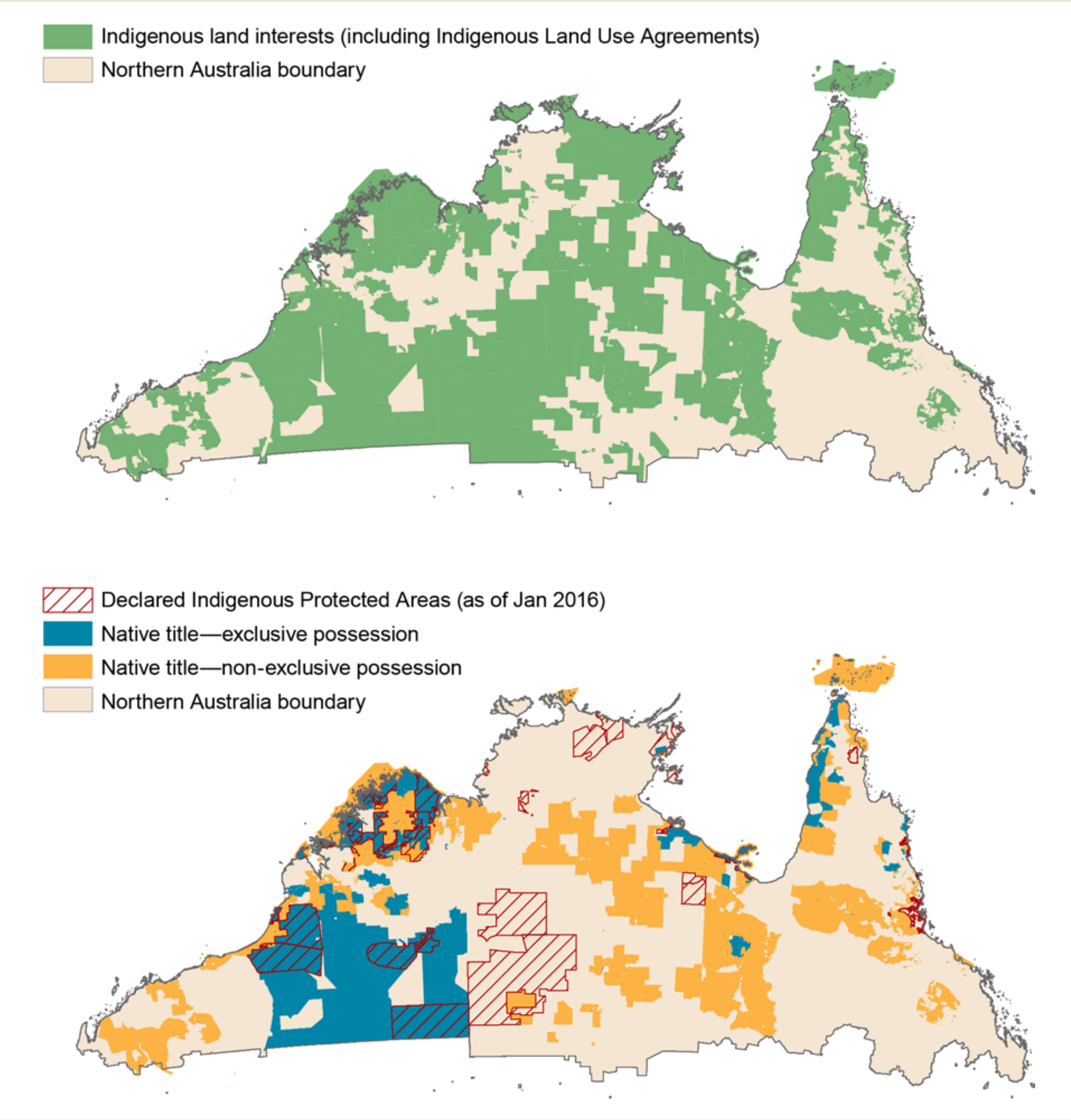
In the Fitzroy Basin, the availability of water is a precondition for the establishment of Indigenous communities (Toussaint et al. 2001). Indigenous land interests in the Fitzroy Basin occur in at least half of the catchment. They include ILUAs and native title, and support diverse land management activities, including protected area management, pastoral leases, food collecting and hunting. Indigenous people make up at least 50 per cent of the population. The high presence of Indigenous people and their close connection with Country support the continuation of language in the population, maintenance of culture, and sustenance of rights and responsibilities in water.

Table LAN7 Indigenous land and sea interests in northern Australia and Indigenous populations in the region

Land tenure	Area (km^2)	Area (%)	Population	Indigenous population	Indigenous population (%)
Northern Australia	3,041,359	100.0	1,062,760	155,951	14.7
Indigenous land interests	1,752,790	57.6	385,552	96,838	25.1
Exclusive possession, NT	464,288	15.3	202,944	41,908	20.7
Non-exclusive possession, NT	720,861	23.7	316,405	56,737	17.9
IPA	359,220	11.8	101,435	23,816	23.5
ILUA	875,855	28.8	776,703	86,782	11.2
Australian tenure, Indigenous	858,221	28.2	132,674	63,847	48.1

ILUA = Indigenous Land Use Agreement; IPA = Indigenous Protected Area; NT = Northern Territory
Source: Petina Pert, CSIRO

Box LAN15 (continued)



Source: Petina Pert (CSIRO), using data obtained from multiple sources, including the Australian Government Department of the Environment and Energy website for declared Indigenous Protected Areas (as of January 2016); the National Native Title Tribunal for native title boundaries; and the Australian Bureau of Statistics for the northern Australia boundary line, used under CC BY 3.0

Figure LAN34 Indigenous land and sea interests in northern Australia

Source: Pethie Lyons and Petina Pert, CSIRO

Acronyms and abbreviations

Acronym or abbreviation	Definition
CSG	coal-seam gas
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
NCRIS	National Collaborative Research Infrastructure Strategy
NRM	natural resource management
Pg	petagram
SOC	soil organic carbon
SoE	state of the environment

Glossary

Term	Definition
acidification	The process of becoming more acidic (i.e. lowering the pH). Soils tend to become acidic through natural leaching and weathering, and as a result of some agricultural practices such as loss of organic material and overuse of nitrogenous fertilisers. The ocean is becoming more acidic as atmospheric carbon dioxide (CO_2) levels rise and the concentration of dissolved CO_2 in sea water increases, forming carbonic acid.
adaptation	Shifts (e.g. in behaviour, management practices, biology) in response to change that support survival; responses that decrease the negative effects of change and capitalise on opportunities.
adaptive management	A systematic process for continually improving policies and practices by learning from the outcome of previously used policies and practices.
anthropogenic	Caused by human factors or actions.
asset	Parts or features of the natural environment that provide environmental functions or services.
biodiversity	The variety of all life forms. There are 3 levels of biodiversity: • species diversity—the variety of species • genetic diversity—the variety of genetic information contained in individual plants, animals and microorganisms • ecosystem diversity—the variety of habitats, ecological communities and ecological processes.
biomass	The quantity of living biological organisms in a given area or ecosystem at a given time (usually expressed as a weight per unit area or volume).
bioregion	A large geographically distinct area that has a similar climate, geology, landform, and vegetation and animal communities. The Australian land mass is divided into 89 bioregions under the Interim Biogeographic Regionalisation for Australia. Australia's marine area is divided into 41 provincial bioregions under the Interim Marine and Coastal Regionalisation for Australia.
biosecurity	Processes, programs and structures to prevent entry by, or to protect people and animals from the adverse impacts of, invasive species and pathogens.
biota	Living organisms in a given area; the combination of flora, fauna, fungi and microorganisms.

Term	Definition
carbon sequestration	Processes to remove carbon from the atmosphere, involving capturing and storing carbon in vegetation, soil, oceans or another storage facility.
caring for Country	Indigenous land and sea management.
Caring for our Country	The Australian Government's central environment program since 2008, which funds environmental management, protection and restoration.
catchment	An area of land determined by topographic features, within which rainfall will contribute to run-off at a particular point. The catchment for a major river and its tributaries is usually referred to as a river basin.
climate change	A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is additional to natural climate variability observed over comparable time periods (as defined by the United Nations Framework Convention on Climate Change).
community	A naturally occurring group of species inhabiting a particular area and interacting with each other, especially through food relationships, relatively independently of other communities. Also, a group of people associated with a particular place.
condition	The 'health' of a species or community, which includes factors such as the level of disturbance from a natural state, population size, genetic diversity, and interaction with invasive species and diseases.
connectivity	Linkages between habitat areas; the extent to which particular ecosystems are joined with others; the ease with which organisms can move across the landscape.
connectivity conservation	Conserving or re-establishing interconnected areas and corridors of vegetation to protect linked ecosystems and the species within them.
conservation	Protection and management of living species, communities, ecosystems or heritage places; protection of a site to allow ongoing ecosystem function, or to retain natural or cultural significance (or both), and to maximise resilience to threatening processes.
corridor	A linear landscape structure that links habitats and helps movement of, and genetic exchange among, organisms between these habitats.
critically endangered (species or community)	At extreme risk of extinction in the wild; the highest category for listing of a threatened species or community under the criteria established by the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).
decline	When the condition of an ecosystem, species or community has decreased to a point where its long-term viability is in question. It usually represents more than just a decrease in numbers of individuals, and describes the result of several interacting factors (e.g. decreasing numbers, decreasing quality or extent of habitat, increasing pressures). In this report, the use of the term is generally prompted by reports that a substantial number of species within a group or community are classified as threatened and there is a high likelihood that more species are likely to qualify for a threatened classification if trends continue. Where 'decline' is applied to elements of environments (e.g. condition of vegetation as habitat) it means that changes have been sufficient to potentially affect the viability of species relying on those elements.

Term	Definition
disturbance	A temporary change in average environmental conditions that disrupts an ecosystem, community or population, causing short-term or long-term effects. Disturbances include naturally occurring events such as fires and floods, as well as anthropogenic disturbances such as land clearing and the introduction of invasive species.
drivers	Overarching causes that can drive change in the environment; this report identifies climate change, population growth and economic growth as the main drivers of environmental change.
ecological processes	The interrelationships among organisms, their environment(s) and each other; the ways in which organisms interact, and the processes that determine the cycling of energy and nutrients through natural systems.
ecology	*See* ecological processes.
ecosystem	An interrelated biological system comprising living organisms in a particular area, together with physical components of the environment such as air, water and sunlight.
ecosystem services	Actions or attributes of the environment of benefit to humans, including regulation of the atmosphere, maintenance of soil fertility, food production, regulation of water flows, filtration of water, pest control and waste disposal. It also includes social and cultural services, such as the opportunity for people to experience nature.
emissions	Output or discharge, as in the introduction of chemicals or particles into the atmosphere.
emissions trading	A system of market-based economic incentives to reduce the emission of pollutants.
endangered (species or community)	At very high risk of extinction in the wild; in danger of extinction throughout all or a portion of its range; criteria are established by the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).
endemic	Unique to a spatially defined area; in this report, used mainly to refer to large bioregions of the continent and marine environment.
endemism	The degree to which species and genes are found nowhere else; the number of endemic species in a taxonomic group or bioregion.
Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)	The Australian Government's main environmental legislation; it provides the legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places.
eutrophication	Excessive nutrients in a body of water, often leading to algal blooms or other adverse effects. *See also* algal bloom.
extent	Areal coverage—for example, of vegetation or sea ice.
extinct (species)	When there is no reasonable doubt that the last individual has died.
feedback	Where the outputs of a process affect the process itself.
fire regime	Frequency, intensity and timing of bushfires.
food web	Interconnected food chains; a system of feeding connections in an ecosystem.

Term	Definition
fragmentation	Isolation and reduction of areas of habitat, and associated ecosystems and species, often due to land clearing.
general resilience	Resilience to unknown or unidentified pressures, disturbances or shocks.
geographic range	Geographical area within which a species can be found.
geomorphology	Scientific study of landforms and the processes that shape them.
global warming	*See* greenhouse effect.
greenhouse effect	Where thermal energy (infrared radiation) that otherwise would have been radiated into space is partially intercepted and reradiated (some of it downwards) by atmospheric greenhouse gases, resulting in warmer temperatures at the planet's surface. The greenhouse effect has supported the development of life on Earth; however, strengthening of the greenhouse effect through human activities is leading to climate change (also known as global warming).
greenhouse gases	Gases that contribute to the greenhouse effect, the most important of which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), short-lived tropospheric ozone (O_3), water vapour, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).
gross domestic product	The total market value of goods and services produced in a country in a given period, after deducting the cost of goods and services used in production but before deducting allowances for the consumption of fixed capital.
gross value added	The value of output at basic prices minus the value of intermediate consumption at purchasers' prices. The term is used to describe gross product by industry and sector. Using basic prices to value output removes the distortion caused by variations in the incidence of commodity taxes and subsidies across the output of individual industries.
habitat	The environment where a plant or animal normally lives and reproduces.
invasive species	Non-native plants or animals that have adverse environmental or economic effects on the regions they invade; species that dominate a region as a result of loss of natural predators or controls.
jurisdiction	An Australian state or territory, or under the control of the Australian Government.
landscape	An area of land comprising land forms and interacting ecosystems; an expanse of land, usually extensive, that can be seen from a single viewpoint.
landscape processes	Processes that affect the physical aspects of the landscape (e.g. weathering of rock formations, erosion, water flow).
major vegetation groups	Aggregation of vegetation into distinct categories; Australia's native vegetation has been classified into 23 major vegetation groups.
millennium drought	The recent drought in southern Australian that lasted from 2000 to 2010 (although in some areas it began as early as 1997).
mitigation	Actions intended to reduce the likelihood of change or to reduce the impacts of change.

Term	Definition
National Reserve System	Australia's network of protected areas that conserve examples of natural landscapes, and native plants and animals. The system has more than 9300 protected areas, including national, state and territory reserves, Indigenous lands, and protected areas run by conservation organisations or individuals.
natural resource management	The management of natural resources such as land, water, soil, plants and animals, with a focus on sustainable practices.
nutrient cycling	Movement and exchange of organic and inorganic materials through the production and decomposition of living matter.
pathogen	A microorganism that causes harm to its living host.
peri-urban	A region between the outer suburbs and the countryside.
pH	A measure of acidity or alkalinity on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline, or basic).
pressures	Events, conditions or processes that result in degradation of the environment.
primary production	The production of organic compounds from atmospheric or aquatic carbon dioxide, principally through photosynthesis.
recruitment	Influx of new members into a population or habitat by reproduction, immigration or settlement. In fisheries management, recruitment represents influx into the fishable part of the stock of a target species.
resilience	Capacity of a system to experience shocks while retaining essentially the same function, structure and feedbacks, and therefore identity.
riparian	Related to riverbanks or lake shores.
run-off	Movement of water from the land into streams.
salinisation	The process of becoming more salty; the accumulation of soluble salts (e.g. sodium chloride) in soil or water. Many Australian soils and landscapes contain naturally high levels of sodium salts held deep in the soil profile.
salinity	*See* salinisation.
sequestration	*See* carbon sequestration.
species	A group of organisms capable of interbreeding and producing fertile offspring.
specific resilience	Resilience to identified pressures, disturbances or shocks.
sustainability, sustainable	Using 'natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations' (*Environment Protection and Biodiversity Conservation Act 1999*, p. 815). 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations Brundtland Commission).

Term	Definition
taxa	A group of one or more organisms classified as a unit. Taxonomic categories include class, order, family, genus, species and subspecies.
taxon	One member of a group; singular of taxa.
taxonomic	Related to the classification and naming of species (taxonomy).
threatened (species or community)	Likely to become endangered in the near future.
threatening process	A process or activity that 'threatens … the survival, abundance or evolutionary development of a native species or ecological community' (*Environment Protection and Biodiversity Conservation Act 1999*, p. 273) and that also may threaten the sustainability of resource use.
threshold	A boundary between two relatively stable states; a point where a system can go rapidly into another state, usually because of positive feedback(s).
trophic	Related to an organism's place in a food chain. Low trophic levels are at the base of the chain (microorganisms, plankton); high trophic levels are at the top of the chain (dingoes, sharks).
value	The worth of environmental assets. Categories of environmental values include: • indirect-use values—indirect benefits arising from ecological systems (e.g. climate regulation) • direct-use values—goods and services directly consumed by users (e.g food or medicinal products) • non-use values (e.g. benevolence) • intrinsic value (i.e. environmental assets have a worth of their own regardless of usefulness to humans).
vegetation assets, states and transition framework	A systematic classification of vegetation condition by the degree of anthropogenic modification from a benchmark natural condition.
vulnerable (species)	At high risk of extinction in the wild; likely to become endangered unless the circumstances threatening its survival and reproduction improve.
Weeds of National Significance (WoNS)	Weeds identified as a threat to Australian environments based on their invasiveness, potential for spread, and socio-economic and environmental impacts; 20 plant species are currently listed as WoNS.
wildfire	An unplanned fire, whether accidentally or deliberately lit (in contrast to a planned or managed fire lit for specific purposes such as fuel reduction).

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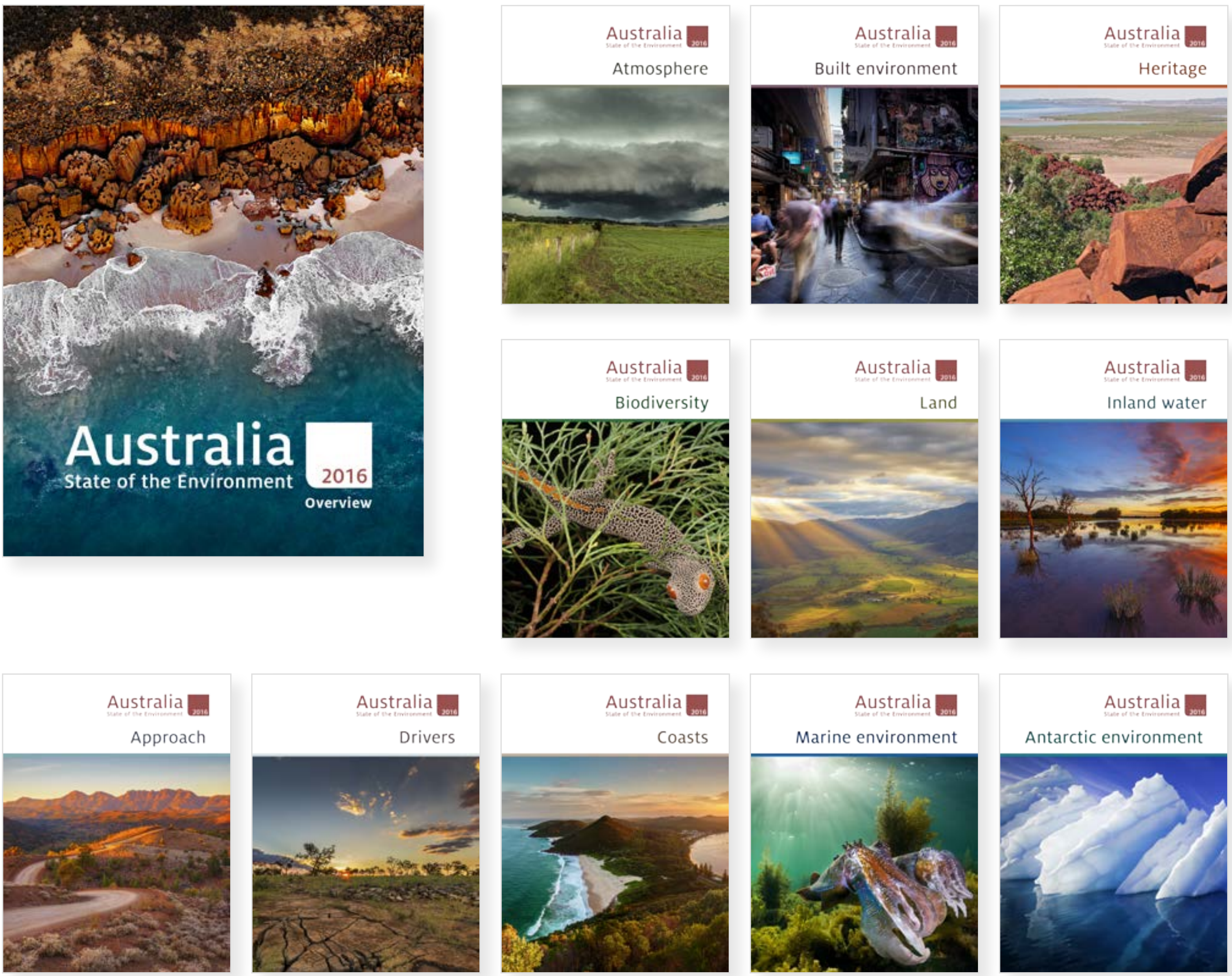
Australia
State of the Environment 2016

Australia state of the environment 2016 (SoE 2016) is an independent national assessment of the state of the Australian environment. It includes 9 thematic reports on atmosphere, built environment, heritage, biodiversity, land, inland water, coasts, marine environment and Antarctic environment. It also includes a synopsis of the detailed theme assessments (*Overview*), highlighting what they mean for the outlook for the Australian environment; a report on the drivers of change in the Australian environment (*Drivers*); and a report detailing the approach to SoE 2016 (*Approach*).



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